DOCUMENT RESUME

ED 164 664 UD 018 914

AUTHOR Baumann, Duane D.; Dworkin, Daniel
TITLE Water Resources for our Cities. Resource Papers for College Geography No. 78-2.
INSTITUTION Association of American Geographers, Washington, D.C. Commission on College Geography.
PUB DATE 78
NOTE 45p.
AVAILABLE FROM Association of American Geographers, 1710 Sixteenth Street, N.W., Washington, D.C. 20009 ($2.50)

EDRS PRICE MF-$0.83 Plus Postage. HC Not Available from EDRS.
DESCRIPTORS *City Problems; Ecological Factors; Ecology; Environmental Education; Majority Attitudes; Pollution; *Public Policy; Urban Environment; *Urbanization; *Waste Disposal; *Water Pollution Control; *Water Resources

ABSTRACT

This paper argues that a re-examination of current goals and methodologies and modifications to management practices are necessary if urban water crises are to be minimized. Three problem areas are focused on: (1) the projection of demand and the estimation of supply; (2) the alternatives for balancing demand and supply; and (3) the management of wastewater. An historical examination of urban water systems is presented to provide an understanding of how water systems have developed in the United States. An evaluation of both private and public institutions is included to shed light on the efficacy of each with respect to water quality. In addition, current problems are further illustrated through an examination of how problems of quantity and quality were resolved in the past. Recommendations for improving the situation are made. A bibliography and numerous tables and charts showing statistical data are included. (Author/EB)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED164664

WATER RESOURCES FOR OUR CITIES

Duane D. Baumann
Daniel Dworkin
Southern Illinois University—Carbondale

U S DEPARTMENT OF HEALTH, EDUCATION & WELFARE
NATIONAL INSTITUTE OF EDUCATION

THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL NATIONAL INSTITUTE OF EDUCATION POSITION OR POLICY

"PERMISSION TO REPRODUCE THIS MATERIAL IN MICROFICHE ONLY HAS BEEN GRANTED BY
Assoc of Amer. Geographers
Salvatore Napoli
TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC) AND USERS OF THE ERIC SYSTEM."

RESOURCE PAPERS FOR COLLEGE GEOGRAPHY
NO. 78-2

UD018914

Copyright 1978
by the
Association of American Geographers
1710 Sixteenth Street, N.W.
Washington, D.C. 20009

Library of Congress Card Number 78–59100
ISBN 0–89291–130–1

FOREWORD

In 1968, the Commission on College Geography of the Association of American Geographers published its first Resource Paper, *Theories of Urban Location*, by Brian J. L. Berry. In 1974, coinciding with the termination of NSF funding for the Commission, Resource Paper number 28 appeared, *The Underdevelopment and Modernization of the Third World*, by Anthony R. deSouza and Philip W. Porter. Of the many CCG activities, the Resource Papers Series became an effective means for permitting both teachers and students to keep abreast of developments in the field.

Because of the popularity and usefulness of the Resource Papers, the AAG applied for and received a two-year grant from NSF to continue to produce Resource Papers and to put the series on a self-supporting basis. The 1977 Series was the first group produced entirely with AAG funding.

In an effort to increase the utility of these papers, the Resource Papers Panel has attempted to be particularly sensitive to the currency of materials for undergraduate geography courses and to the writing style of these papers. The present Panel continues to affirm the original purposes of the Series, which are quoted below:

> The Resource Papers have been developed as expository documents for the use of both the student and the instructor. They are experimental in that they are designed to supplement existing texts and to fill a gap between significant research in American geography and readily accessible materials. The papers are concerned with important concepts or topics in modern geography and focus on one of three general themes: geographic theory; policy implications; or contemporary social relevance. They are designed to complement a variety of undergraduate college geography courses at the introductory and advanced level.

The Resource Papers are developed, printed, and distributed under the auspices of the Association of American Geographers. The ideas presented in these papers do not imply endorsement by the AAG.

Many individuals have assisted in producing these Resource Papers, and we wish to acknowledge those who assisted the Panel in reviewing the authors' prospectuses, in reading and commenting on the various drafts, and in making helpful suggestions. The Panel also acknowledges the perceptive suggestions and editorial assistance of Jane F. Castner of the AAG Central Office.

Salvatore J. Natoli
Association of American Geographers
Editor, Resource Papers Series

Resource Papers Panel:

John F. Lounsbury, Arizona State University
Mark S. Monmonier, Syracuse University
Harold A. Winters, Michigan State University

ACKNOWLEDGMENTS

This monograph was written as a source of information for undergraduates who are interested in resource management, and to encourage more geographers to become involved in the complex issues of environmental planning. Although the authors assume full responsibility for the content and style of this report, the critical appraisal and support of many persons contributed significantly. We are grateful to the support of Holcomb Research Institute, Indianapolis, Indiana during earlier drafts of this volume. The comments of the following persons were constructive during subsequent revisions: Nancy Baumann, David Holtz, Carl Leivo, Steve Miller, Jerome Milliman, Gerald Reynolds, Scott Sebastian, David Sharpe, and Frank Thomas. We are grateful to Daniel Irwin for preparing the graphic materials, and to Salvatore Natoli, for his diligence in raising questions of clarity and for his penchant for detail. Finally, to Barbara Pearson we are appreciative of her patience and perseverance in typing earlier revisions of this monograph.

D. D. Baumann
D. Dworkin
Carbondale, Illinois

PREFACE

Critical Question of Urban Water Supply and Wastewater Management in the United States

Contemporary municipal problems of water supply and waste treatment, while often considered separately, are inevitably linked. Once we recognize the linkage between water supply and waste treatment, opportunities arise for reusing treated wastewater to supply the city when alternative sources are not readily available. These opportunities are not simple. We must answer questions of public health, acceptability, and economics before cities can reuse substantial portions of their wastewater.

The expertise of a single profession, such as engineering, can no longer solve contemporary municipal water supply problems nor can reliance upon a single alternative, e.g., the construction of new reservoirs and/or wells. Today, we require information from numerous disciplines, including both physical and social sciences, and the need for synthesis is paramount. Geography can contribute to this growing need arising from the new, diverse, and complex human-environment problems; hence, traditional programs in many undergraduate and graduate programs necessarily will be revised in order to train the new geographer to contribute better to imaginative, creative, innovative new knowledge and policies.

CONTENTS

I. INTRODUCTION 1
II. URBANIZATION AND WATER RESOURCES 1
System Ownership 2
Sources of Supply 2
Competition for Supply 2
The Experience in the East and the West 3
Changing Urban Demands for Water 3
Water Quality Standards 4
Safe Drinking Water Act of 1974, Public Law 94–523 5
Water Pollution Control Act Amendments, P. L. 92–500 6
III. DEMAND FOR WATER SUPPLY AND WASTEWATER TREATMENT 7
Future Demand 7
Projecting Demand and Estimating Supply 8
The Components of Demand 9
The Residential Sector 10
The Commercial Sector 10
The Industrial Sector 10
Methods of Demand Projection 10
Time Series and Projections 11
Models and Simulations 11
Holistic Methods 12
Summary of Demand Forecasting 13
Estimation of Water Supply 13
Surface Water Yields 13
Groundwater Yields 14
Use of Supply Projections 15
Wastewater Flow Projections 16
IV. PLANNING ALTERNATIVES: INCREASING SUPPLY AND DECREASING DEMAND 16
Alternatives That Increase Supply 16
Increase System Capacity 16
Divert Surface Water 16
Develop New Groundwater Supplies 17
Conjunctively Use Surface and Groundwater 18
Improve Efficiency 18
Reduce Evaporation 18
Detect Leaks 18
Modify Weather 18
Desalinize Water 19
Renovate Wastewater 19
Public Health Factors 20
Public Acceptance 20
Economic Feasibility 21
The Role of Reuse 21
Alternatives That Decrease Demand 22
Metering 22
Pricing 22
Restrictions on Use 24

V. MANAGEMENT OF WASTEWATER 25
Legislative History of Sewage Treatment 25
Evaluating The Current Program 25
Pollutants and Their Effects 26
Degradable Wastes 26
Non-Degradable Wastes 26
The Oxygen Sag Curve 26
Effect of Dissolved Oxygen Levels 27
Non-Degradable Wastes 27
Wastewater Treatment 27
Primary Treatment 28
Secondary Treatment 28
Tertiary Treatment Processes 28
An Alternate Method, Land Treatment 28
Sludge 28
Meeting the Goals of P. L. 92–500 and 95–217 29
VI. SOCIAL ACCEPTANCE OF ALTERNATIVES: PROFESSIONAL AND PUBLIC 31
Professional Bias? 31
Public 31
VII. SUMMARY AND CONCLUSIONS 32
BIBLIOGRAPHY 33

LIST OF FIGURES

1. Reduction of Typhoid Fever in Philadelphia Following Treatment of the Water Supply 4
2. Nature of Adjustments Made by 39 Massachusetts Communities During the 1963–66 Drought ... 8
3. Actual Water Use & 1924 Projection For Detroit Metropolitan Area, 1900–1960 8
4. Cost of Forecasting Versus Cost of Inaccuracy 11
5. Population Growth of the Nation, Indiana & Indianapolis by Decades 12
6. Population Model 13
7. Subsurface and Groundwater Phase of the Hydrologic Cycle 15
8. Schematic Primary Oxygen Sag Curve for Two Different Organic Waste Discharges 26
9. Regional Assessment of Percentage of Sewered Population Served With Secondary Treatment by July 1, 1977 29

LIST OF TABLES

1. Estimated Water Use 1975 and Projected Requirements by Purpose, Continental United States .. 3
2. Streamflow Compared With Current Withdrawals and Consumption 7
3. Water Use by Various Sectors of Demand 10
4. Alternatives for Balancing Supply and Demand for Municipal Water Supply 17
5. Frequency Distribution of Unaccounted-For Water in Cities 18
6. Geographical Distribution of Municipal Reuse 20
7. Average Residential Water Rates 1975 23
8. New WSSC Water/Sewer Rate Schedule 23
9. Sewer User Charges, 1976 30

I. INTRODUCTION

Planning for municipal water supply and the treatment of wastewater is a drastically different challenge today than in the past. The reasons are complex and border on the speculative. First, with urbanization and higher standards of living, the per capita demand for water has increased markedly—there is, however, some doubt whether this trend will continue. Second, new reservoir sites are becoming increasingly scarce, as was so clearly evident in the New York Metropolitan Area's experience. Third, groundwater resources have been exploited fully in many areas and are now available only as a supplemental source. Fourth, technological, economic, and political problems of interbasin transfer of water have proliferated. Fifth, higher energy costs have been translated into higher production costs. Sixth, the current high cost of money (interest rates) increases the consequences of premature or overinvestment in new supplies. Seventh, the Safe Drinking Water Act (P. L. 93–253), the Federal Water Pollution Control Act Amendments of 1972 (P. L. 92–500), and the Clean Water Act of 1977 (P. L. 95–217) have established the natural mandate for strict water quality considerations for municipal water supplies.

It is this complex set of new challenges that we must consider in planning effectively for municipal water management. In planning for future demand, complex questions about quality and quantity, and social, economic, and environmental costs will exert a strong influence on the choice of alternatives. Our understanding of these interactions is far from complete; for example, the increasing amounts of both natural and manufactured substances in our waters may have potentially serious effects on human health. Water planners consequently find themselves responsible for the solution of a totally new set of problems, the importance of which is difficult even for experts to determine. This Resource Paper focuses on three problem areas where it is necessary to re-examine current goals and methodologies and to modify management practices if we are to minimize the occurrence of water crises in our cities: 1) the projection of demand and the estimation of supply; 2) the alternatives for balancing demand and supply; and 3) the management of wastewater.

Before we direct our attention to these problems, an historical examination of urban water systems will provide the necessary understanding of how our water systems have developed, the evaluation of both the public and private institutions will shed light on the efficacy of each with respect to water quality, and the way in which problems of quantity and quality were solved in the past will supply us with some insight about current problems.

II. URBANIZATION AND WATER RESOURCES

The development of public water supply systems in the United States can be dated back to 1652 when a private corporation built a twelve-foot square reservoir in Boston. It was designed to meet the needs of water supply and fire protection for the neighborhood. It was not a financial success (Blake, 1956).

This early attempt did not trigger a rush to provide municipal facilities for urban areas. During the early history of the United States, public water supply systems grew slowly. Individual wells, collective wells, or small impoundments served the communities. By the beginning of the nineteenth century, only seventeen cities had public water supply systems. Convenience provided the early impetus for the adoption of public water supply systems. The need for a public system was not compelling. Water use was low and wells serving individual homes or neighborhoods were adequate. Two conditions assured the adequacy of the wells. First, there was a minimum of paved areas and as a result water could infiltrate through the soil. In addition, individual treatment systems refined the water withdrawn for supply. In farm communities or areas with mixed farm and suburban populations, individual wells or small surface impoundments could (and still do) provide adequate water supplies without needing an extensive public system to serve a dispersed population. The pressure of increasing urbanization provided the driving force for development of public systems.

In urbanization, the rural character of an area gives way to large-scale housing developments, shopping

centers, industrial buildings, and an extensive network of paved streets and sidewalks. Such an urban agglomeration increases the need for water within a relatively small area. And at the same time, the amount of paved surface decreases the water returned to the underlying aquifer (an underground area of permeable material that can store and supply water) by decreasing the infiltration of surface water. When individual wells are no longer adequate, public water systems must rely on well fields or surface supplies.

The nineteenth century was a period of urbanization during which the nation's population gradually shifted from predominantly rural to urban. In this period public water supply systems began to serve an increasing portion of the total population. As the century began, public systems supplied only a part of the populations of Philadelphia, Baltimore, and New York. By 1860, the sixteen largest cities in the United States, each with populations of over 50,000, had public water supply systems. In addition, 120 smaller communities also provided public supplies. By 1895, the number of community supply systems had increased to over 3,000 (White, 1969).

System Ownership

Private investors started the early community water systems in the large cities with the exception of Philadelphia. These early systems, however, all became publicly owned. Public ownership was encouraged by what today seems an unlikely organization. The American Medical Association through its Committee on Public Health issued the following assessment of the role of private enterprise in the provision of municipal services (Blake, 1956:268):

> The introduction of an abundant supply of water is so intimately connected with the health of a city that the municipal authorities should rank this among the most important of their public duties. In connection with this matter, the committee is deeply impressed with the importance of confining the execution and management of such great public works as a supply of water, gas, and drainage to the city authorities. The public welfare is too deeply interested in their faithful performance, safely to permit them to pass into the hands of incorporated companies, who, however highminded they may be, look to them as sources of revenue, and not as objects of public good.

By 1860 there was a clear separation between the ownership of large and small systems. Only four systems in the largest sixteen cities were owned by investors, the balance were publicly owned systems. In contrast, two-thirds of the systems in smaller communities were private ventures.

Sources of Supply

As the process of urbanization continued, the growing population required more and more water. There are only two sources of water, surface supply or groundwater. Drilling techniques and high capacity pumps required to extract groundwater in large quantities were not available so the emphasis was on surface water supplies. Those nearest the city were used first. As the use of water exceeded the capacity of local sources, cities extended their search for supplies farther afield.

The process continues today. New York City, for example, draws water from upper New York State. Boston uses water diverted from western Massachusetts, whereas Denver, Colorado Springs, and Aurora, Colorado use water gathered on the western slopes of the intercontinental divide as a source of municipal supply. The transfer of water for municipal supply has reached its zenith in Los Angeles. The Metropolitan Water District, the marketing agency for imported water in the Los Angeles area, distributes water transported from the Owens Valley and from the Colorado River, each requiring over 300 miles of aqueducts, and also from northern California, a distance of over 400 miles. To bring the water to the Los Angeles area substantial quantities of energy are required for pumping water over the intervening mountain ranges.

Although surface water was the major source of supply from the inception of public water systems, groundwater sources were not insignificant. They made up over one-third of the supply in 1900, but the proportion gradually declined. By 1950, one-quarter of the total use was from groundwater. That proportion of total use has continued to decline slowly, with groundwater representing twenty-four percent of 1975 public water supply. Projections are for the proportion of groundwater making up public supply usage to decline gradually (U.S. Bureau of the Census, 1975).

Groundwater supplies, in contrast to surface flows, are nearly always in or near the cities in which they are used. They usually represent only a supplementary source of supply, although some large cities (Miami, Florida; Newark, New Jersey; St. Paul, Minnesota; and Salt Lake City, Utah) are exclusively or primarily served by groundwater sources.

Competition for Supply

Were urban areas the only users of water there would be few problems. Urban systems, however, are only one of a number of users vying for a fixed supply. Some of the uses of water are not competitive. For example, boating or swimming does not diminish the quantity of water, although each may introduce problems of water quality. The uses that do not require water to be diverted are classified as in-stream uses. These include recreation, navigation and hydroelectric power generators. If the water must be diverted for use it is classified as a withdrawal. In most instances, some of the water is returned to the streams, commonly referred to as return flow. The water not returned because of evaporation and percolation is considered consumed. The difference between the amount withdrawn and the amount of return flow is the consumptive use. Where the consumptive use is low in relationship to the amount withdrawn, the return flow is available for downstream users. An example of a low consumptive use is in min-

ing of minerals whereby nearly ninety-eight percent of the water withdrawn is returned to the stream. Irrigated agriculture in contrast consumes over half the water withdrawn.

The total withdrawals for all uses in the United States in 1975 were nearly 340 billion gallons a day (bgd). Of this amount nearly a third was for consumptive uses. Agriculture represented nearly half of all withdrawals and over eighty-five percent of consumptive use. Energy production withdrew twenty-seven percent of all withdrawals but consumed less than two percent. Municipal systems represented less than ten percent of all water withdrawn and seven percent of all water consumed.

Surprisingly, projections are for withdrawals to decrease over the next twenty-five years. This is primarily because the manufacturing sector, which in 1975 withdrew nearly fifteen percent of all water in 1975, is projected to decrease this to only six percent by the year 2000. The projected decrease in withdrawals is attributed to the effects of stricter quality requirements of P.L. 92–500 for water discharged to the streams. We can assume that industry will recycle more water and practice conservation to avoid the increasingly strict water quality requirements for return flows.

Although withdrawals are projected to decrease, projections for consumptive use should rise from the present level of 106 bgd in 1975 to 135 bgd by the year 2000. This will mean a gradually increasing competition for water by municipal systems (Table 1).

TABLE 1. ESTIMATED WATER USE 1975 AND PROJECTED REQUIREMENTS BY PURPOSE, CONTINENTAL UNITED STATES (Billions of Gallons Daily)

Type of Use	Withdrawals			Consumption		
	1975	1985	2000	1975	1985	2000
Municipal and Domestic	28	32	36	7	8	9
Manufacturing	51	23	19	6	9	15
Energy Production	89	95	80	1	4	11
Mining	7	9	11	2	3	3
Agriculture	157	165	153	86	92	92

Source: Modified from U.S. Water Resources Council, 1978.

The Experience in the East and the West

To understand the water management problems of cities in the United States it is necessary to understand the difference between the experience of the humid East and the arid West. As a result of the arid environment, the historical development of laws governing municipal supply in the West was different from the East. Water had to be harvested from larger areas of watersheds to supply each person. This meant larger projects, at greater distances from the users, and at greater expense. To accommodate these differences, different laws arose governing the diversion and use of water. In the East, water law is based on the principal of riparian rights, which gives the water rights to adjoining landowners who must not diminish the water in quantity or quality. The law has been interpreted freely to allow almost unlimited diversion and degradation of streams.

The West started with a different code of law, the doctrine of prior appropriations, which is often characterized by the phrase "first in time, first in right." This law allows claims to be filed on water in a stream and, in some states, on groundwater independent of ownership of land. The law allocates the water on the basis of the time of filing: once filed, a claim has to be perfected, that is, the water has to be diverted and put to beneficial use. Beneficial use is defined broadly; in general, proof of beneficial use can be supported if no water is allowed to flow off the land of the appropriator. Seventeen western states have laws based on the doctrine of prior appropriations. These laws differ in many respects. In some cases, once the right has been established, it can be sold for use off the original site. In others, the right to transfer water use is limited to the use at the place and for the purpose of the original filing.

The prior appropriations doctrine, although necessary for development of western water resources, does have some critics. Without such a law, those making the major investments required to develop the water would not be assured of the source of supply. Users upstream could divert the flow for their own uses. The law, however, does encourage premature investment in water resources because of the first in time, first in right concept.

Changing Urban Demands for Water

Although the laws governing supply of water were different, demand in both the East and the West grew rapidly. The total amount of water furnished by public water utilities from 1900 to 1960 had approximately doubled every twenty years (a growth rate of approximately 3.5 percent) from a total use in 1900 of three billion gallons daily to twenty-two billion gallons daily in 1960. The rate of increase in total water use since 1960 has decreased. Between 1960 and 1970 water use increased at only half the previous rate (U.S. Bureau of the Census, 1975).

In part the increase in use resulted from increases in the number of persons served. The number of persons living in urban areas has been growing rapidly. The 1910 census showed less than half of the population, about forty million persons, living in urban areas; but the 1920 census showed for the first time that a majority of persons were living in places classified as urban. The urban population tripled from 1910 to 1960 from forty-two million to over 125 million persons and, in addition, water service was extended to suburban areas.

Although serving more people, the systems were popular and per capita use soared. The Philadelphia system, which charged a $5 yearly flat rate, became concerned about waste and in 1806 passed a law against allowing the water to run unnecessarily. Both Boston and New York, which had planned for a use of thirty

gallons per person per day, were exceeding the planned usage (Blake, 1956). Baltimore reported a steady rise in per capita use that reached ninety-five gpcd (gallons per capita per day) by 1895 (Sewage Commission of Baltimore, 1895). Philadelphia reported per capita use of seventy-two gallons in 1885 and 162 gpcd in 1895 (Hazen, 1897).

Waste was blamed for much of the early heavy water use. In Boston, the practice of allowing water to flow during the cold weather to prevent freezing of pipes caused some of the high usage. (Indianapolis residents repeated this practice in the winter of 1976–1977 at the behest of the Indianapolis Water Company because of the record cold weather.) Hazen (1897), in a study of the water supply practices of Philadelphia, estimated that water use could be cut by nearly forty percent if waste were eliminated.

The popularity of water systems can be measured by their use. One rough measure of usage is the per capita demand. This is the total amount of water delivered by a system divided by the total population served.

The figures on gallons used per capita daily conceal more than they reveal because they include not only residential use in an urban water system but also industrial and commercial use. There is often considerable confusion between the per capita use and the per person residential use, which is always much lower. Other measures of use, more meaningful in comparing systems, are measures of residential, commercial, and industrial use. Such data, although not always available, provide more exact methods of system evaluation.

The national averages of per capita use have been rising steadily. In 1900, reported usage was ninety gpcd which had risen to 140 gpcd by 1954 (Symons, 1954). Surveys by the American Water Works Association (AWWA) reported per capita use of 156 gallons in 1965 and 189 gallons in 1970.

Because of varying methods of calculation, the per capita use estimates vary widely from city to city. In the 1970 AWWA survey, the range of daily per capita use was from 30 to 552 gallons. Fifteen percent of the utilities reported use of less than 100 gpcd and in seven percent of the communities use exceeded 300 gpcd. The generally upward trend in per capita use has slowed and some utilities are reporting a level or declining trend (Patterson, 1976). In some systems industrial withdrawals have decreased because of the increasingly stringent requirements of P.L. 92–500 on the quality of wastewater discharged.

This short history of the adoption and use of an urban convenience, piped water supply, reveals its slow, early growth. As increasing urbanization forced piped water supply on cities, its advantages became apparent and per capita use grew rapidly. So far we have ignored the factor of water quality, which also played a part in the history of urban water systems.

Water Quality Standards

Whereas public convenience provided the impetus for the original formation of water supply systems, public health considerations soon became important. The role of water was not perceived as a carrier of disease, but as a medium to mitigate epidemics. In the late eighteenth century, New York, Baltimore, and Philadelphia used water liberally to wash streets and gutters during a yellow fever epidemic assuming that the resulting clean streets would ameliorate the epidemic (Blake, 1956).

Even before Pasteur's experiments led to the germ theory of disease, the safety of water began to be a source of concern. The taste and odor of water was often objectionable. Chemical analysis could provide no guidance in the detection of unsafe water. In 1881 one of the leading chemists of the time, Ira Remser, head of the Massachusetts Institute of Technology, advanced the need for protected watersheds, where no sewage could find its way into the water. Remsen was instrumental in establishing the first sanitary engineering curriculum and a laboratory for pollution research (White, 1969).

In the late nineteenth and early twentieth centuries, filtration and chlorination of public water supplies began. In 1871 Poughkeepsie, New York adopted filtration (Fair, Geyer, and Okun, 1966). In Lawrence, Massachusetts a water quality laboratory established by the State Board of Health in 1886 developed and began using sand-filtration as a method of controlling disease (Rowland and Heid, 1976).

In 1908 Jersey City, New Jersey first instituted chlorination (National Research Council, 1977). Chlorine added to water destroys both bacteria and viruses if maintained at a sufficient level over a designated period of time. In addition, if a chlorine residual is maintained in the water, organisms that infiltrate the system during distribution will be destroyed.

Providing for public water supplies and for their control by protecting the source of water and treating the supplies by filtration and chlorination, have had a profound effect on the rate of water related diseases. Figure 1 shows the decline in the incidence of typhoid fever in

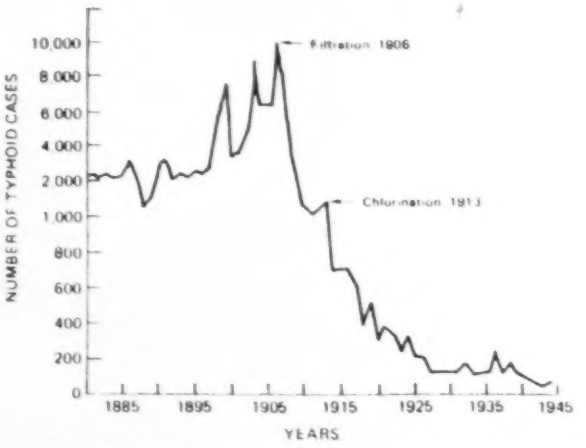

Figure 1. Reduction of typhoid fever in Philadelphia following treatment of the water supply. Source: Kilbourne and Smillie, 1969: 220.

Philadelphia over the period during which filtration and chlorination of the water supply had taken place.

The reduction of typhoid and cholera deaths to very low levels does not mean that these or any other diseases transmitted by water have been eliminated. There is, in fact, a disturbing residual disease problem connected with public water supplies. In the period between 1938 and 1945, there were 327 separate incidences of waterborne disease outbreaks, such as gastroenteritis and dysentery, which affected over 100,000 persons (Eliassen and Cummings, 1948).

The causes of the outbreaks were most often a result of inadequate filtration or chlorination by untrained and unsupervised plant operators or of cross connections, that is, inadvertent mixing of lines carrying water supply and sewage. Groundwater is often considered safer than surface supplies; however, in the same period nearly 4,000 cases of disease were attributed to groundwater sources (Eliassen and Cummings, 1948).

A more detailed study was made of the fifteen-year period, 1946–1960. During these years there was a decline in the number of reported cases of waterborne diseases and the number of persons affected even though infectious hepatitis and shigellosis were identified and classified as waterborne diseases in this period (Weibel *et al.*, 1964).

Further tabulations of disease caused by public and private water systems indicated 125 incidents between 1961 and 1970 (Bardo and Cassell, 1971) and seventy between 1971 and 1973 (Craun and McCabe, 1973). The 1961–1970 period documented nearly 19,000 gastroenteritis cases alone. During this same period, seven outbreaks of waterborne disease (ten percent of all recorded) were on Indian reservations (Bardo and Cassell, 1971).

A comparison to determine trends in disease related to public water supplies should be undertaken with caution. With the increase in mechanisms and agencies for reporting, such as the National Communicable Disease Center, and the Environmental Protection Agency, the percentage of disease outbreaks reported will doubtless increase.

In focusing on the problems of public water supply in controlling waterborne pathogens, it is easy to ignore the effectiveness of treatment. Currently, the acute danger from public water supply systems is minimal. Deaths attributed to disease transmitted by public systems have declined to very low levels. Between 1961 and 1970, only seven deaths were attributed to public water supply systems. Of these, four were from water supplied to Indian reservations (Bardo and Cassell, 1971).

Safe Drinking Water Act of 1974, P.L. 94–523

Although municipal systems have provided a supply of water with vastly decreasing potential for the transmission of acute disease-causing pathogens, some industrial plants are discharging potentially toxic chemicals. In addition, toxic materials may be present in the runoff from agricultural fields and city sewers. These include four major groups of substances which are carcinogens (substances or agents producing or inciting cancer):

Petroleum Products - arising from petroleum refining wastes, waste oils from industry and transportation, runoff from roads and from the oil-based sprays used to apply pesticides.

Coal Tars - arising from gas coke, tar, tar paper, and wood preserving plants.

Amino-Nitro Compounds - from dye, rubber, pharmaceutical, and plastic manufacturing.

Pesticides, Herbicides, and Soil Sterilants - from agricultural-chemical manufacturers and users.

In addition to these substances, the action of chlorine on other noncarcinogenic materials forms compounds which may become carcinogens. The concentration of these substances is often low, measured in parts per billion (ppb). For example, chloroform concentrations in five communities receiving water supply from the Ohio and Mississippi Rivers were from 37 to 152 parts per billion (Harris, 1974).

Can chemicals in such low concentrations cause cancer? The original investigation of this question focused on the population of New Orleans, whose water supply comes from the Mississippi River. Because the river drains more than forty percent of the land area of the United States, New Orleans, near the mouth of the river, was an ideal site for such a test. The Environmental Defense Fund conducted the study and issued its report on November 6, 1974. The report states: "presumptive epidemiological evidence accumulated . . . suggest[s] a significant relationship between cancer mortality . . . and drinking water obtained from the Mississippi River" (Harris, 1974:1). Additional studies by independent research groups have confirmed the statistical relationship between organic contaminants in drinking water and increased cancer rates (*Science*, 1977).

Although the study of the New Orleans water supply system has not as yet resulted in any changes in the water supply of that city, it did have an effect on national legislation. On December 16, 1974, six weeks after the release of the report, Congress passed the Safe Drinking Water Act that charged the Environmental Protection Agency with implementing the act in three stages. The first stage consists of a set of interim regulations, the second a revised set of regulations to be established based on a National Academy of Sciences (NAS) study completed in July of 1977. The final regulations are to be based on the NAS study.

The Environmental Protection Agency promulgated the National Interim Primary Drinking Water Regulations in December 1975 which became effective at the end of June 1977. These regulations set maximum contaminant levels for ten inorganic constitutents, turbidity, coliform organisms, pesticides, and radioactivity, and required the identification of treatment technologies that could be used to achieve these levels.

The established maximum contaminant levels for

organic pollutants identified six chemicals, all of which are pesticides. These are lindane, texaphene, 2, 4-D, silvex, and methoxychlor.

Although the regulations appeared impressive, they merely confirmed the status of the contaminant levels allowable. The interim report did not consider any of the other 247 organic pollutants that the Environmental Protection Agency had identified in the 1975 report to Congress nor did it include a limitation on chloroform, a recognized carcinogen that was identified in the drinking water of eighty cities tested. The Environmental Defense Fund instituted a suit against the Environmental Protection Agency for not implementing the spirit of the law.

The Environmental Defense Fund wanted the Environmental Protection Agency to require the use of an established technology that would provide an effective barrier against all the organic pollutants, i.e., the filtration of the water through activated carbon. The Environmental Protection Agency Water Supply Research Division itself had been advocating the use of activated carbon. It would cost large utilities an estimated $4 to $7 annually to treat the water for a household of four (*Science*, 1977). In January 1978, this was finally required by the Environmental Protection Agency for cities of over 75,000 persons.

In the past, water quality issues have been solved by management practices, such as protected watersheds, and technological treatment methods, such as filtration and chlorination. Still there are communities that have lagged behind and have not adopted proven technologies. Worcester, Massachusetts, for example, a city of nearly 200,000, is served by a water system with no filtration and minimum levels of chlorination. Water from the city cannot be used by interstate carriers such as buses or trains. The new legislation, the Safe Drinking Water Act, provides for the first time federal regulation of the quality of the public water supply.

Water Pollution Control Act Amendments, P.L. 92–500

Under Public Law 92–500, the Federal Water Pollution Control Act Amendments, the government launched a major program to improve the quality of the nation's streams. An enormous effort is underway currently, to provide the best practicable technology; later, to provide the best available technology; and finally, to achieve zero-pollutant discharge for all municipalities and industries.

The first goal was to be reached by mid-1977. At that time less than one-third of all municipal systems could meet the goal. One estimate prepared for Congress indicates that it will require an investment by the federal government of $4.5 billion annually until 1993 before all communities would be able to meet the 1977 standards. Under P.L. 92–500 the federal share is seventy-five percent; therefore the state and local communities would be required to provide over $1 billion annually. By 1993, this will mean a cumulative investment of over $500 for each person in the country. In addition, operating costs are high. One study showed the annual operating costs of sewage plants in the Delaware River Basin to be nearly thirty times greater than the annual nonfederal capital costs of the sewage plants (U.S. Congress, 1977).

There is little evidence that the benefits of the program are equal to the costs. There is considerable question whether alternatives to the present treatment technologies have been seriously considered even though encouraged by both P.L. 92–500 and the Clean Water Act of 1977. For example, only one major urban area, Muskegon, Michigan, is using land treatment for wastewater. There is also considerable doubt whether the step-by-step approach to zero-discharge is not wasteful, that the overall effect on water quality would be better if fewer integrated plants designed to meet the zero-discharge requirements should be built rather than the massive program of building the over 8,000 additional individual plants required to meet the July 1, 1977 goal under P.L. 92–500. Recognizing the impossibility of communities meeting these goals, Congress passed a new law, the Clean Water Act of 1977, P.L. 95–217, which amends and delays the goals of P.L. 92–500. This new law encourages innovative methods of treatment by increasing the federal contribution toward constructing such projects. The act also specifically sets aside money that rural and small urban communities can use for "alternatives to conventional sewage treatment works." The new act also extends the time limit for compliance with the 1977 standards to no later than July 1983 if the federal share of the financing is delayed, thus delaying completion of the treatment facility (P.L. 95–217). To encourage nonstructural methods of waste treatment, nonstructural treatment alternatives are eligible for eighty-five percent federal cost sharing.

III. DEMAND FOR WATER SUPPLY AND WASTEWATER TREATMENT

Water demands in the United States are undergoing profound changes. As previously noted, rates of withdrawal are projected to decline while consumptive use rises. There is one constant; the estimated average annual streamflow in the conterminous United States is approximately 1,325 bgd, and it is doubtful that this amount will be changed greatly within the next ten, twenty, or fifty years. Hence, the rate of change in demand will determine the extent of our water resource management problem.

Future Demand

The exact rate of increase in demand and the nature of the demand for water in the future remains highly uncertain. As the U.S. National Water Commission (1973:3) aptly recognized, there are dangers and problems in basing planning decisions on a single projection:

> How much water will be used, where, and for what purposes will depend on the policies that are adopted. A range of 'alternative futures' is possible, depending upon population levels and distribution, per capita energy consumption, rate of national income growth, technological development, water pricing policies, consumer habits and lifestyles, various governmental policies, and other variables.

For one of these variables, water pricing policies, research has demonstrated that increases in price would lower demand for residential use primarily because of a decline in lawn sprinkling (Linaweaver *et al.*, 1966a), whereas an increase in the generation of thermal-electric and nuclear power would raise substantially the demand for water.

Today, several regions of the country face imminent threats of shortages, especially the Rio Grande and the Great Basin regions where withdrawals exceed mean annual streamflow (Table 2). In the Lower Colorado River Basin consumptive use is greater than mean annual runoff, the deficiency being made up by groundwater and water transfers.

As the process of urbanization continues, a large demand for water within a relatively small area will add to the pressure for greater efficiency in the present use as well as create intense competition for the presently

TABLE 2. STREAMFLOW COMPARED WITH CURRENT WITHDRAWALS AND CONSUMPTION

Region	Annual Flow Available				Consumptive Use 1975	Withdrawals 1975
	Mean Annual Streamflow*	50% of the Years*	80% of the Years*	95% of the Years*		
North Atlantic	157.3	155.2	123.9	96.7	2.3	23.4
South Atlantic-Gulf	228.0	219.2	164.1	121.8	4.9	24.5
Great Lakes	72.7	71.7	57.3	44.9	2.6	42.8
Ohio	178.0	178.0	141.0	105.0	1.8	35.0
Tennessee	40.8	40.8	35.9	31.4	0.3	7.4
Upper Mississippi	121.0	121.0	91.8	65.3	1.1	12.4
Lower Mississippi	433.0	433.0	282.0	202.0	4.0	14.6
Souris-Red Rainy	6.0	5.6	3.4	NA	0.1	0.3
Missouri	44.1	43.2	29.9	17.6	15.5	38.0
Arkansas-White-Red	62.6	59.1	37.4	21.6	8.0	12.9
Texas-Gulf	28.3	22.9	12.3	6.3	11.3	16.9
Rio Grande	1.2	0.6	0.3	0.2	4.2	6.3
Upper Colorado	10.0	10.0	7.0	3.9	2.4	6.9
Lower Colorado	1.6	1.6	1.4	1.2	4.6	8.9
Great Basin	10.5	9.8	6.7	4.6	3.8	8.0
Columbia-No. Pacific	255.3	254.3	213.3	179.7	11.9	37.5
California	48.2	45.2	30.4	20.0	26.6	39.6
Conterminous United States*	1,242.1	1,219.1	895.1	679.3	105.4	335.4
Total United States*	2,158.7	2,127.9	1,698.3	1,389.7	106.4	338.5

*Totals will not add up because the regions are not mutually exclusive.
Source: Streamflow data from U.S. Water Resources Council, 1978.

available supply, e.g., water for our urban population versus the demands for irrigation. In 1975, our urban areas used seven bgd representing seven percent of the total consumptive use; by 2000, consumptive use in urban areas is expected to rise to nine bgd, which will continue to account for seven percent of all such use (see Table 1). Although withdrawal use for cities is projected to rise to thirty-six bgd in 2000, the proportion it represents of all withdrawal uses (eight percent) is seen as declining slightly to seven percent—primarily because expected increases in water use by manufacturing will account for an eleven-fold increase in consumptive use of water for energy production.

If present water supply practices continue, shortages will be most acute in our urban areas. Cities are presently importing water from distant sites. As sites for new reservoir construction become increasingly scarce and resistance to interbasin transfers grows, new policies will necessarily be formulated and implemented. Again, we rely upon the final report of the National Water Commission (U.S. National Water Commission, 1973:1):

> To increase efficiency in water use and to protect and improve its quality, and to do these things at least cost and with equity to all parts of our country . . . require major changes in present water policies and programs.

In response to the increase in demand, cities have traditionally chosen to increase the available supply, except under emergency conditions. Alternatives that would lower demand have, in general, been ignored. For example, the most common response of forty-eight Massachusetts communities during the drought of the early 1960's (aside from the unenforced pleas for restrictions on water use) was to plan for increase in supply, new sources, improvements in present supply, emergency sources, and a cloud seeding experiment. Those adjustments directed toward reducing demand were rarely considered or adopted (Figure 2).

This traditional reliance upon technology designed to modify the environment, instead of policies directed toward changing our schedule of demand, has been equally pronounced in another water resource problem. White (1973:161) has succinctly noted: "For a long time it was out of the question for a planning officer to study any way of dealing with flood losses other than by constructing engineering works or by providing relief."

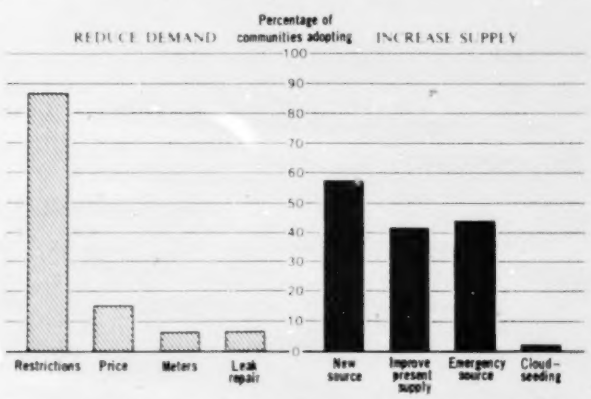

Figure 2. Nature of adjustments made by 39 Massachusetts communities during 1963–1966 drought. Source: Russell, Arey, and Kates, 1970: 71.

Projecting Demand and Estimating Supply

Municipal water systems require forecasts of demand to provide for orderly development. When the sources of supply are easily obtained, the forecasts can be for a short term; but as the easy opportunities close to the city disappear and as the city must develop capacity at greater distances and at higher costs, the demand forecasts become more critical and must be prepared for more extended periods. As the projection of demand becomes more important, the estimation of the available and projected supply also becomes more important. Underestimating yields (the amount of water a system can provide) can result in unnecessary or premature investment, although overestimates can result in unexpected shortages.

Forecasting water demand is a complex procedure that should involve economic, environmental, and engineering considerations. In the future, as cities move to complex forecasting methods, geographers, because of their broad ranges of interests, should have an increasing role in the process.

Today in most cities, forecasting is a simple process that involves only extrapolating the past and projecting pumpage rates or population and per capita use for twenty-five to fifty years into the future. The city of Detroit, for example, prepared a long-term projection that substantially overstated actual use (Figure 3). Such projections often result in premature or un-

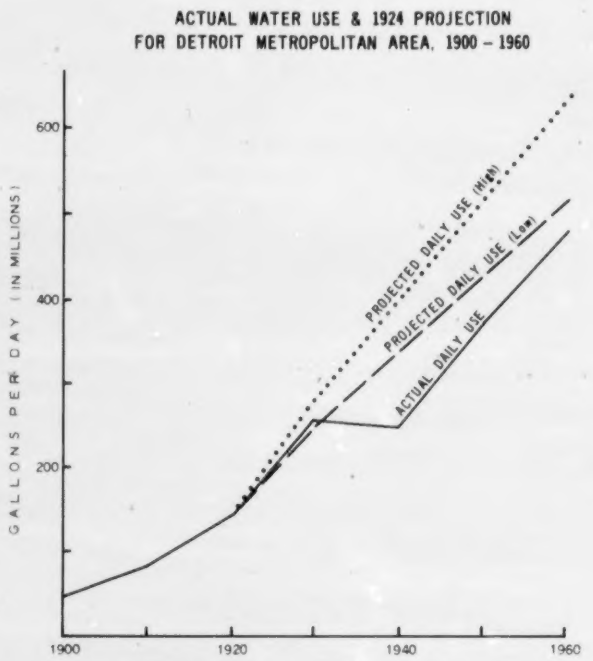

Figure 3. Source: White, 1970.

necessary development of additional sources of supply.

Demand forecasts can be prepared by projecting water use from the past or by estimating the changes in the components that make up demand. The most common elements in component projections are population and per capita use. Other forecasts estimate changes in economic activity, expansions of the system to serve additional areas, reduction of leakage, fluctuations in price, additional industrial use, or changes in technology or lifestyle to predict future demands for water. For example, one set of projections prepared in 1937 for the Indianapolis Water Company considered the effect of the Depression on population growth and per capita water use. The projections indicated that although population growth was not affected by the Depression, per capita use had decreased and would grow again only with the return of "good business conditions" (Alvord, Burdick, and Howson, 1937).

In addition to considering individual variables that affect demand, residential, industrial, and commercial uses can be projected separately. These projections, which are similar to the projections of aggregate usage, can be based on extrapolations of past trends or on estimations of future changes in individual variables. Such separate projections can increase the accuracy of forecasting. Therefore, before reviewing various available methods of projections, it is useful to consider the major components or sectors of water demand.

The Components of Demand

The most common categories of municipal water using customers are residential, commercial, and industrial. Depending on the composition of a municipality and its geographic location, each sector may represent a varying proportion of total use.

The Residential Sector. Residential water demand, which on a national average accounts for over sixty percent of all municipal use, was studied extensively in a program at Johns Hopkins University from 1961 to 1966. The study areas were homogeneous sections of cities in which average and peak water demands were recorded over a two-year period. The study forecast the average demand for a residential unit as a function of water price, house value, number of persons per dwelling unit, and evapotranspiration (Linaweaver, Geyer, and Wolff, 1966a; Howe and Linaweaver, 1967; Howe, 1968; Hittman Associates, 1969). This study shows that as price increases, demand declines; that as the value of the house and the number of persons occupying it increase, the water use will rise; and that lawn watering, as measured by the rate of evaportranspiration, is a significant variable in estimating use.

Several other studies have attempted to measure residential water demand according to a variety of parameters. In one such examination in Colorado Springs, Colorado, the variables accounting for more than seventy-five percent of residential demand for twelve years of record were season, price, population, departure from mean rainfall, and time (Dworkin, 1975). As in the Johns Hopkins study cited above, the same variables were important. Season and departure from mean rainfall reflected the increased use during the summer sprinkling period and during dry periods. The additional variable, time, reflected changes in use, in this case increases, not reflected by the other variables. This might result from increased adoption in the home of water using devices such as automatic washing machines or increased lawn areas in new home developments.

The Commercial Sector. On a national basis, the commercial sector, including many heavy water using establishments such as laundries, hotels, restaurants, and car washes, accounts for approximately twelve percent of total water use, although such an estimate excludes some institutional users such as schools (McPherson, 1976). The Johns Hopkins study (Wolff and Geyer, 1966) is the most extensive investigation of the use of water by the commercial sector. The study recorded total water use for several commercial and institutional users by three-month periods, by day, and by hour. These records of use were compared with design capacities for annual maximum day and peak hours. In all cases there was as much as a two-fold difference between design capacity and actual maximum use (Table 3). Such overdesign is another indication of the engineering attitude toward overestimation that was exhibited in preparing the demand forecasts for the city of Detroit cited earlier.

When projecting the commerical demand for water, the analysis should include existing water use and projections made of demands of new or enlarged commercial establishments. Price of water is another factor which must be considered carefully in commercial use. For example, in Colorado Springs, Colorado, water use declined with increased price in the commercial sector more than in any of the other sectors of demand (Dworkin and Baumann, 1974). Although we do not know why this is so, we assume that large commercial users began to restrict use and to reuse water as prices increased.

The Industrial Sector. Industrial use of water represents over twenty-five percent of all public water supply users. Some municipal systems have no industrial users, whereas in others industrial users predominate. In a discussion of industrial supply, Sherwani (1964:194) states:

> It is extremely difficult to forecast future demand of industrial water. Very few reliable data are available on the costs, pattern of water use and water technology of self-supplied industries. Industries vary greatly in their requirements of water . . . Technological process changes permitting a reduction in the quantity or quality of water used, changes in production functions eliminating water use altogether, and the changes in industrial water use technology to increase reuse and recycling will have major impacts on net water requirements. It is, therefore, not possible to say that a product requires a specific quantity of water.

Sherwani indicates that technological change will be influenced by the increasing costs of water, which will decrease the use of water per unit of industrial output. White (1970), on the other hand, finds that industrial

TABLE 3. WATER USE BY VARIOUS SECTORS OF DEMAND

Type of Establishment or Institution	Selected Parameter	Annual Water Use (gpd/unit)		Maximum Day Water Use (gpd/unit)		Peak Hour Water Use (gpd/unit)	
		Expected	Design	Expected	Design	Expected	Design
Primary and Secondary Schools							
Public Elementary	gpd/student	5.38	8.67	9.68	13.0	49.1	52.4
Public Jr. High	gpd/student	5.64	9.75				
Public Sr. High	gpd/student	6.63	12.2	19.6	25.2	121	127
Private Elementary	gpd/student	2.27	6.09	3.10	6.92	25.7	29.5
Private Sr. High	gpd/student	10.4	18.6	15.7	23.9	38.7	46.9
Combined (grades 1–12)	gpd/student	8.49	18.7	16.8	27.0	51.3	61.5
Colleges							
Students in residence	gpd/student	106	179	114	187	250	323
Non-resident students	gpd/student	15.2		27.0		57.8	
Hospitals	gpd/bed	346	559	551	764	912	1120
Nursing Homes and Institutions	gpd/bed	133	209	146	222	424	500
Apartments							
High Rise	gpd/occupied unit	218	322	426	530	745	849
Garden Type	gpd/occupied unit	213	315	272	374	671	773
Hotels	gpd/sq. ft.	0.256		0.294		0.433	
Motels	gpd/sq. ft.	0.224	0.326	0.461	0.563	1.55	1.65
Office Buildings General offices less than 10 yrs. old	gpd/sq. ft.	0.093	0.164	0.173	0.244	0.521	0.592

Source: Linaweaver, Geyer, and Wolff, 1966b: Table 4–1.

managers give only minimal consideration to the costs of water, and are more responsive to the costs of waste treatment.

Whether from increased costs of supply or increased costs of waste treatment mandated by pollution control regulations, the costs of both water intake and discharge will rise. As Sherwani predicted, these rising costs should then result in adopting technology to decrease water use per unit of production. Wolman and Bonen (1971) have also forecast such results and they see increasing rates of recycling of all industrial categories. The requirements for increasingly stringent water quality requirements of P. L. 92–500 are projected to decrease dramatically the withdrawal of water by industry. Projections are for withdrawals to decrease by more than half between 1975 and 1985 and by a further twenty percent by the year 2000 (U.S. Water Resources Council, 1978).

Methods of Demand Projection

In selecting a method for projecting future water demand, the forecaster may choose from a wide variety of techniques ranging from the simple to the complex. Sophistication should not be confused with reliability of results. Although fifty-year forecasts based on elaborate techniques may appear precise, the history of most long-term forecasts indicates a low probability of accuracy. For example, in the previously cited study of Detroit, the actual water use after 16 years was lower than the low projection by as much as forty percent, and was seventy-five percent less than the high projection.

The lack of precision notwithstanding, projections are required for long-term planning. The planner and the plan user should be aware of the limitations in any long-term projection, no matter how sophisticated the technique. Such awareness might result in selecting, to the extent possible, smaller increments of capacity with an ongoing review of projections of future change. Russell, Arey, and Kates examined the possible losses that would result if such projections failed to reflect growth rates accurately, and concluded that "*Only in relatively unusual circumstances would even a serious under-estimate of demand growth imply very large*

losses, if planners take the reasonable precautions of checking their assumptions" (1970:162) (emphasis in original).

Where there is a relationship between the cost of preparing a projection and its accuracy, the planner should select that methodology for which the cost of providing an accurate projection is equal to the cost imposed by the limitations in accuracy (Figure 4). The relationship between cost and accuracy does not always exist nor does the available input data often provide the basis for elaborate projections. In such cases, simple statistical models or graphic representations are most appropriate.

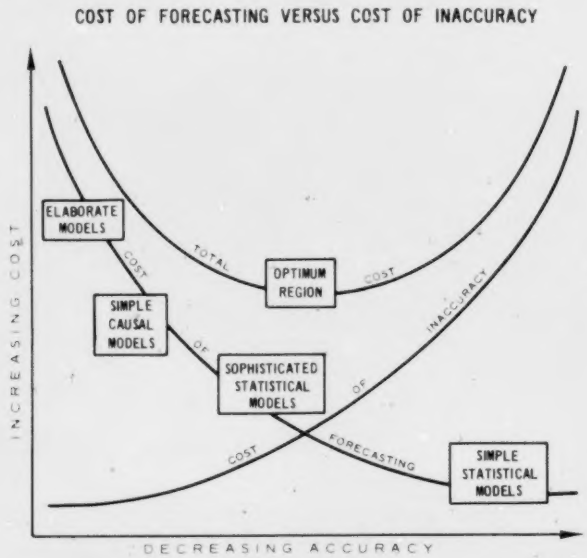

Figure 4. Source: Chambers, Mullick, and Smith, 1971.

From the approximately 150 different forecasting techniques available for estimating future water demands, three major categories can be identified (Mitchell *et al.*, 1975). These include time series and projections, models and simulations, and holistic methods. Each can be used to project aggregated data such as total water pumped to individual sectors of demand (residential use) or to components of demand (population).

Time Series and Projections. The class of time series and projections includes those techniques based on the assumptions that forecasts can be extrapolated, patterns of change recognized, or probabilities of events predicted from historical record. Extrapolation, the most common method of forecasting, may be graphic or mathematical. Graphic techniques involve plotting the historical data on arithmetic, probability, or logarithmic paper, and extending the plot into the future. One interesting curve-fitting method that has gained wide use is the logarithmic curve first proposed by Verhulst in 1838 and later independently rediscovered by Pearl, based on his observation of the growth of fruit flies in a jar. The fruit flies originally grew very rapidly because the food supply and the space available was large in relation to the number of individuals. As the space became more crowded and access to the food supply was more difficult the population increase slowed.

In using this method, the forecaster is assuming that municipalities, like fruit flies, go through a period of slow growth in the initial and late stages, which are separated by a period of rapid expansion, and that growth is determined by some unknown "natural" factor.

Mathematical techniques can also be used to extrapolate trends. The objective of mathematical analysis is to extract from the data the mathematical equation that will best conform to the historical data. The method most commonly used is simple regression analysis in which historical data are used as the dependent variables and time as the independent variable. More sophisticated mathematical techniques include computer programs, which select the equation that best fits the historical data.

If the data base for an area is inadequate for extrapolation, projections for a larger area can be used to provide a basis for estimating future population growth in the study area. Known as the "ratio method," this technique relies on the logical assumption—true for most U.S. communities—that areas which have similar underlying conditions affecting growth, and which in the past have exhibited comparable trends in population and employment, are likely to continue to share such trends in the future. Ratios can reflect either a fixed or changing relationship over time.

Figure 5 demonstrates one application of the ratio method. Here, Alvord *et al.* (1937) compared the growth of Indianapolis, the State of Indiana, and the United States, and indicated the convergence of the growth rate of all three. Note the conclusion of the Pearl forecast. The population of Indianapolis is finally projected at a rate that decreases slightly in comparison with that of the United States. In general, however, despite its logical basis, the ratio method should be used with caution since it incorporates all errors in the original forecast, and transfers these errors to the forecast of the study area.

The impact of random factors complicates the extrapolation process. For example, residential water use during the summer months depends upon rainfall conditions. When rainfall is low, people irrigate their lawns and gardens more frequently than in periods of high rainfall. In another case, industrial use of water depends upon fluctuating economic conditions. Unless researchers can identify and consider such relationships, forecasts based on elevated usage during drought periods and periods of unusual economic activity will be in error.

Models and Simulations. Models and simulations are useful in forecasting situations in which the state of a system depends upon the changes and interrelationships among the components of that system. For example, one simple model commonly used in water demand projections is a population forecasting model in which the three components are births, deaths, and migration

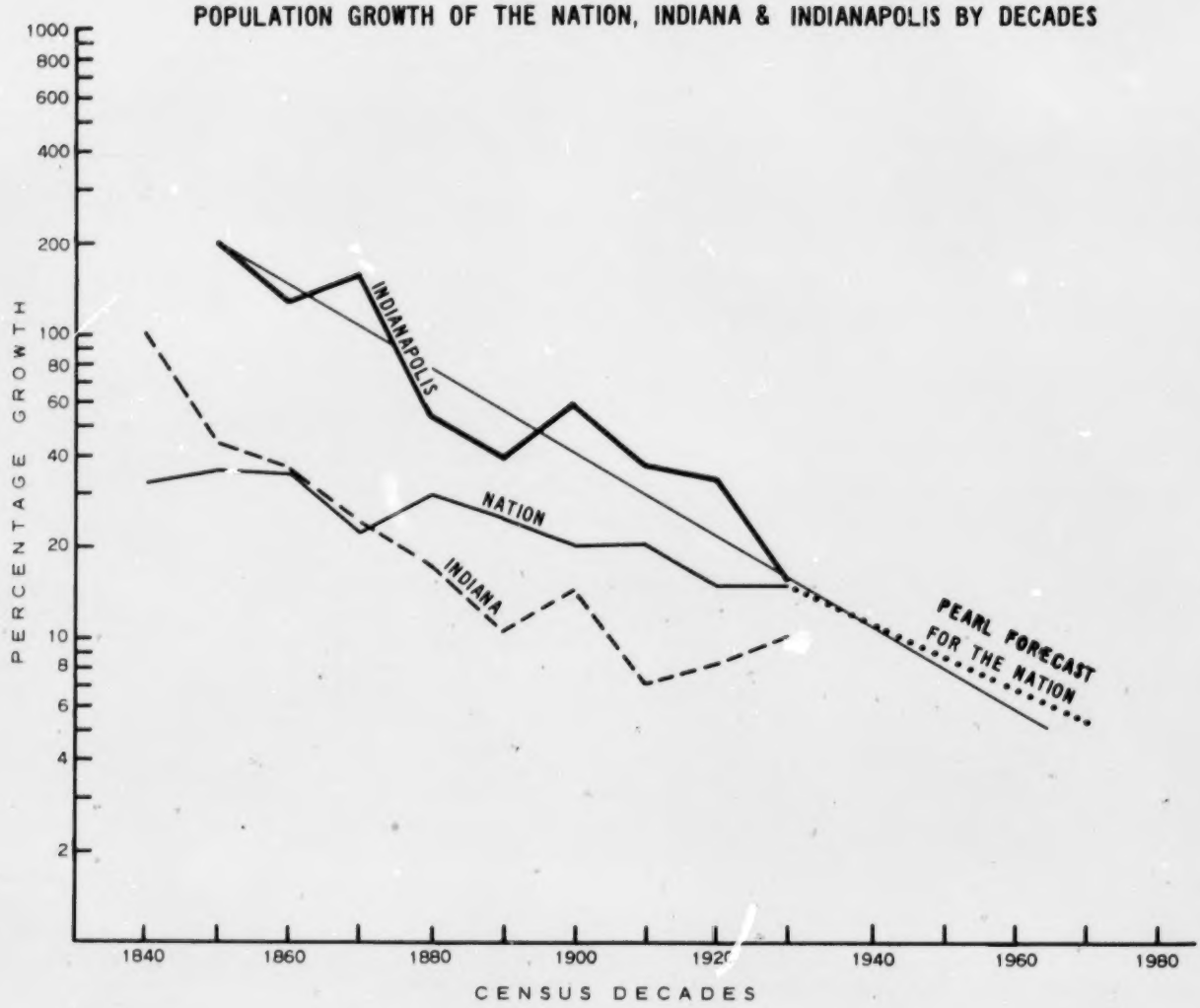

Figure 5. Source: Alvord, Burdick, and Howson, 1937.

(Figure 6). A model developed by Howe (1968) uses lot size, income, sewers, price, evapotranspiration, and persons per dwelling unit to predict residential water use. Whitford (1972) suggests a model that involves a number of variables: regulations, pricing policy, education campaigns, housing trends, supply costs, and changes in technology.

In using Whitford's model the forecaster assigns probabilities to each variable. For example, highest demand would result from a lack of water use regulations, declining block rate pricing, the absence of an education campaign designed to restrain use, a suburban housing pattern, the low cost of water, and a lack of technological changes aimed at reducing water consumption. Whitford (1972:83) explains that this type of model has the advantage of producing "a probability distribution of future water use rather than a single number. This distribution would emphasize the uncertainties of forecasting, facilitate staged development, and permit water systems to be designed for calculated probability of failure . . ." The Whitford model, although conceptually a major advance in forecasting techniques, depends upon estimating probabilities of events and their effects, which is extremely difficult and often entirely subjective.

Holistic Methods. In holistic forecasting the forecaster draws together everything known about components of demand and their probable changes and integrates these into a projection. Holistic methods of demand projection use scenarios, which are views of the future. Scenarios often rely on other forms of projection as inputs, and are then formulated on the basis of either single or alternative assumptions of the future. In discussing the value of scenarios, Mitchell *et al.* (1975) state:

> In general [holistic methods] are the least developed of the forecasting techniques . . . Without doubt,

20

> however, they represent the area where the most professional attention is currently being paid. In the opinion of many . . . holistic forecasting techniques are the leading edge of the art and emerging science of looking ahead.

To date, this potentially important approach has received little significant practical application.

Summary of Demand Forecasting

In the past, demand projection has relied on simple extensions of pumpage rates or per capita use. Because demand for water was growing rapidly, there was little need for increased sophistication in forecasting demand where water was readily available. Now, however, the rate of increase in water use has slowed; water in many cases is not readily available and requires much more extensive investments which will be reflected in increased price. This in turn will decrease use. Under these circumstances, forecasting techiques should be developed and used to reflect better these present conditions.

Estimation of Water Supply

Calculations can be made of the potential water supply from sources ranging from aquifers to small streams and entire river basins. Indeed, with the advent of large-scale computer simulations these calculations have reached a high degree of sophistication. Any such calculations are at the mercy of our still incomplete understanding of meteorology, hydrology, and climatology. As Herschleifer *et al.* (1960:372) noted in their study of New York: "Here we have a case where predictions about the social phenomena of use, while off the mark, still proved far more reliable than predictions as to the natural phenomena of supply." Thus, as in the case of demand projections, highly sophisticated predictive models of supply are not necessarily superior to relatively straightforward graphic or mathematical techniques.

In discussions of supply, water resources are generally divided into surface water and groundwater. The distinction is made because the technologies for, and the constraints upon, the exploitation of each are markedly different. Thus, we will treat surface water and groundwater separately. It must be recognized that the two sources are interconnected, however, with surface flows usually the above-ground extension of a groundwater reserve. Thus, as we extract groundwater, surface flows will decline.

Surface Water Yields. Water diverted from rivers and streams and stored in reservoirs accounts for about seventy-five percent of the U.S. municipal water supply. In planning to use surface supply the important questions are: Is there enough water available? How

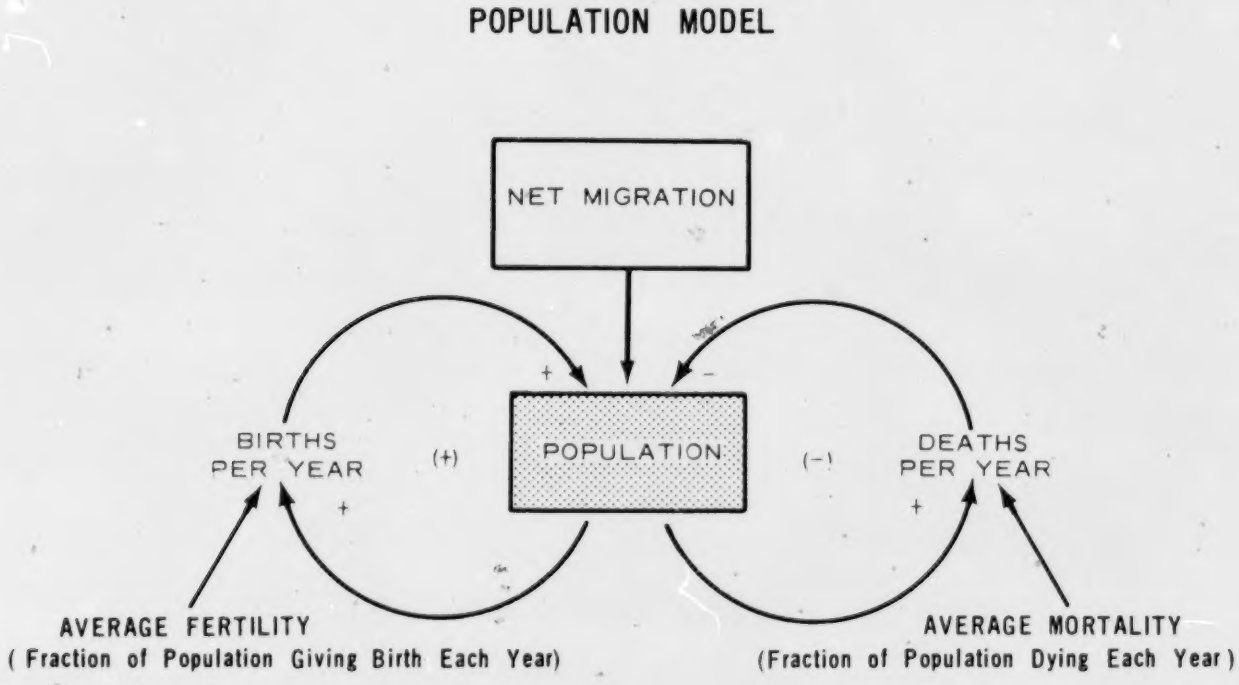

Figure 6. Source: Mitchell *et al.*, 1975.

much storage will be required to provide it? and finally, How assured is the supply? To answer these questions there is a wide range of techniques to determine the amount of water available from a given quantity of storage, the yield, and the assurance that drought conditions will not restrict the quantity.

All three factors—storage, yield, and the assurance—are interrelated. Higher levels of storage increase the amount of water that can be supplied. As storage levels increase, yields increase. The amount of yield can approach, but except under special circumstances discussed below, can never exceed the mean annual flow of the stream.

There is also a relationship between yield and assurance. As assurance levels decline, that is, as the worst low flow conditions are exempted from the calculations and yields are allowed to decline during these periods, the storage levels can decline.

At ninety-five percent assured-yield, thirty months out of a fifty-year planning period can have yields lower than the target estmate; whereas a ninety-eight percent safe-yield exempts only twelve months.

Two basic methodologies are available for calculating the storage-yield relationship. The first are designated sequential methods since they assume that the unique sequence of flows in the historical record represents a suitable assumption about how the future flows will affect the relationship between storage and yield. The other, nonsequential methods analyze the historical record and determine the probability of the occurrence of flows.

From these data a family of curves can be constructed that represents the probability that a low-flow will not be exceeded for any given period. It is then possible to calculate the amount of storage required to ensure supply for any given level of desired certainty or assurance.

Nonsequential analysis using a computer program to calculate desired releases and inflows over an extended period is a more complicated and potentially accurate mode of analysis. Such a program might be a simulation of the physical system and might also include the simulation of factors affecting demand, such as drought, or it could represent a mathematical programming analysis in which the computer model would analyze the system without simulating either the inflow sequence or demand (Hydrological Engineering Center, 1975).

All estimates rest upon the assumption that the historical record will be typical of the future. Some notable exceptions prove that this is not always so. The Colorado River was apportioned between upper and lower regions on the bases of historical flows which were never equalled. The Colorado apportionment will become troublesome as the actual use by the upper region approaches the amount apportioned. In Chile, reservoirs constructed on the basis of a short record of flows could not be filled because the flows occurring after construction were lower than the historical record indicated (Wollman, 1968). These two instances are dramatic examples of overestimation. Since underestimation only means that reservoirs will be fuller than might otherwise be expected, the results are not so evident.

Groundwater Yields. Groundwater accounts for twenty-five percent of municipal supply nationally with many municipal systems being completely served by groundwater. Groundwater exists in aquifers which consist of porous rock or unconsolidated deposits of sands and gravel. There are two basic types of aquifers, confined and unconfined (Figure 7).

Confined aquifers are sealed off from the surface by a layer of material relatively impervious to water. Water percolating down through the soil thus cannot reach the confined aquifer. Such formations have limited areas of recharge, often at great distances from the main body of the aquifer. Wells that top confined aquifers are named artesian wells and often, because the water is under pressure, it flows from the well without pumping. This is often mistaken as a necessary condition of an artesian well.

Unconfined aquifers are formations which receive and store water that has percolated through the upper layers of soil. If the upper layers of the soil are dry, some water remains in the soil held by surface tension. The balance, under the influence of gravity, continues to move downward until it reaches a zone that is completely saturated. If the material in the zone of saturation is one from which the water can be extracted by pumping, it is an aquifer. Unconfined aquifers are often associated with surface water; streams usually represent the level of the water table. During periods with no surface runoff, stream flow is maintained by water being discharged from the water table.

The materials that make up aquifers can be either consolidated rocks such as sandstone and limestone or unconsolidated materials such as sand and gravel. These make suitable materials because they are highly porous and the pores are interconnected. The porosity provides for large amounts of water storage, whereas the interconnection means the water can move through the rocks.

The amount of water that can be removed on a sustained basis from an aquifer is equal to the rate of recharge. The aquifer can be considered an underground reservoir which in the long term can supply only the mean inflow. Like a reservoir it can supply for a limited period more water than is being recharged. How much more depends on the size of the aquifer, the capacity of the pumps removing the water, and the rate of movement of the water through the aquifer material to the well.

Often no consideration is given to sustained yield in the use of confined aquifers; the water is simply mined and once used will no longer be available. This occurs where the amount of water in storage is very high and the rate of recharge is very low. In the lower Colorado Basin, for example, the cities of Tucson and Phoenix, Arizona are rapidly depleting the aquifer by withdrawing water at a rate that exceeds recharge. As a result the levels of groundwater are declining from seven to ten feet per year. This has the immediate effect of requiring more energy to lift the water and will eventually deplete the aquifer.

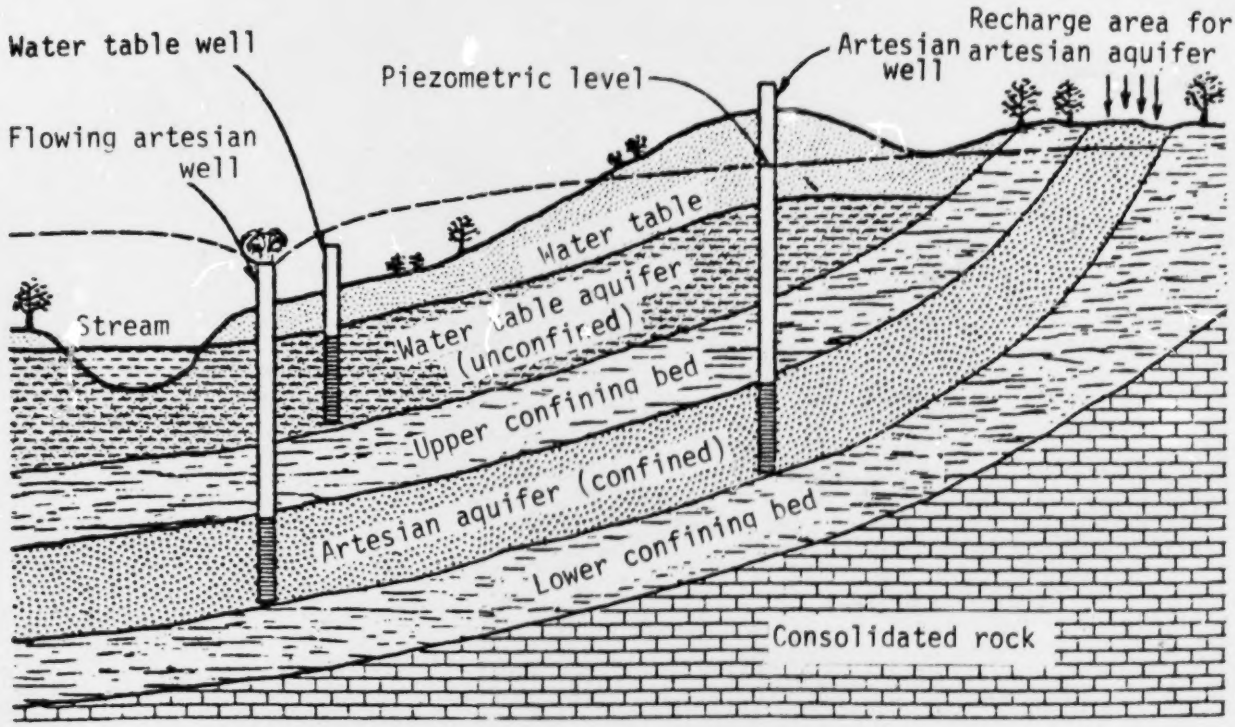

Figure 7. Subsurface and groundwater phase of the hydrologic cycle.

The rate of recharge of unconfined aquifers is a function of the filtration of water through the overlying soil and of the degree of association with a stream. As water is withdrawn from the aquifer, water in the groundwater table will flow to fill the void. The water in unconfined aquifers usually migrates to a stream and when unconfined aquifers are pumped the streamflows are reduced.

It is more difficult to predict the yields of confined and unconfined aquifers than for surface supplies. Accurate forecasts of how much water can be withdrawn depend upon the size and composition of the aquifer, and on the placement, capacity, and pumping rates of wells that share the common resource. Such forecasts are often prepared by the use of computer models of the aquifer.

Use of Supply Projections

When evaluating projections of supply, we often forget that these are estimates. Whereas the language of supply is precise, such as 100 million gallons daily, 98 percent assured, etc., the underlying methodology used to arrive at these estimates is at best, tenuous. It would be instructive if those responsible for managing or evaluating water systems would translate historical data records into recurrence intervals of periods of low flow on which they base their calculations.

The evidence of the accuracy of projections of supply is not reassuring. During a period of drought in New England, most, if not all, water systems could provide more water than the estimates of yield (Russell, Arey, and Kates, 1970). On the other hand, some systems in Illinois could not provide estimated yields during a period of low flow (Hudson and Hazen, 1964).

Social scientists and engineers often taken opposite sides on the issue of yields of municipal systems. The former charge that conservative engineering practices cause underestimation of yield, whereas the latter argue for more rigorous methods of yield calculation. This somewhat empty academic debate obscures the real nature of yield calculations. They are estimates and are subject to error in calculation, i.e., in sampling, the historical record may not be representative or may not take into account variations in climatic conditions.

There is a further reason why yield estimates are suspect. For those cities that rely on surface water and that have built a succession of projects, the combined yield is calculated as the sum of the yields of each individually. This simply is not correct. Reservoirs are really only averaging devices to alter the temporal distribution of flows and, with a given capacity, will produce higher yields as the stream variability declines. Since streams are never completely correlated, that is, the low- and high-flow periods will not correspond exactly in timing and effect, the result will be a decrease in the overall variability of the source of supply and an increase in the combined yield. The only condition for realizing the increased yield would be the ability to

withdraw water from any of the reservoirs to supply the community as opposed to servicing specific areas from each reservoir (Dworkin, 1977).

Wastewater Flow Projections

Not only are the projections of use affecting the decisions on water supply but the inevitable linkage means that wastewater treatment facilities consistent with the estimates of the future use of water are also being planned and built. As the projections of use are either under- or overestimated, so will the treatment facilities built to treat the estimated waste flow be too small or too large.

There is one linkage between water supply and waste treatment that has not been recognized in the past but that will become increasingly important in the future—the charges for sewage treatment required under Public Law 92–500, Section 204. Under the law, appropriate operation and maintenance costs are to be borne proportionately by users, that is, the more sewage discharged, the higher the charges. Since sewage is the inevitable end product of most residential water users, and since metering sewage flow is a difficult problem, many cities have billed customers for sewage charges on the basis of their use of water. This dramatically increases the cost of using water. For example, in the suburban Washington, D.C. area, sewer charges are twenty-five percent higher than the cost of water so that a customer using an average of 1,000 gallons of water daily pays $1.05 for water and $1.31 for sewer use (WSSC, 1978).

For those communities that are for the first time being charged for sewer usage, the sewer use charge will no doubt be considered as a simple increase in the price of water. Under these conditions, the evidence from a number of studies is clear—customers will react by decreasing use. The relationship between price and use is discussed more fully in Chapter Five.

IV. PLANNING ALTERNATIVES: INCREASING SUPPLY AND DECREASING DEMAND

Aside from doing nothing and accepting shortages, a municipality may employ those alternatives that either increase supply or change demand, or choose a combination of both (Table 4). In the past, water management has concentrated on increasing supply, with major emphasis on the construction of reservoirs and other structured means to increase total system capacity. These extensions of the water suppy system frequently occurred during times of system stress, such as drought, or when there were expectations of a continued increase in demand.

Although extensions of system capacity continue to be of great importance, the growing economic, political, and environmental problems associated with this approach have led to a search for alternative methods to balance supply and demand. Recently, combinations of alternatives are beginning to take precedence over reliance on single-method approaches in municipal water management. In these next two sections we will examine planning alternatives: first those that increase supply and then those that decrease demand.

Alternatives That Increase Supply

To increase supply we will examine five alternatives: increase capacity, improve efficiency, modify weather, desalinize water, and finally renovate wastewater.

Increase System Capacity

In the past, when municipalities faced water shortages their initial responses were to increase the overall capacity of the water supply systems. The technologies are well tested and they produce the expected results. However, this approach involves many problems. Opportunities for increased expansion are limited in many areas of the country, and as cities reach out farther for new supplies they often come into conflict with other governmental units or individuals over the appropriation of a new surface or groundwater source. We will examine the implications of using both ground and surface water and then how systems can increase the amount of water available by conjunctive use of both ground and surface water.

Divert Surface Water. Water diverted from streams presently supplies seventy-five percent of the total urban supply. Recent projections indicate that the proportion will increase slightly in the future. Expanding urban areas have already captured the water available from the best local sources; those sites remaining are generally less favorable and their development more costly. As a result, many larger cities, especially those in areas susceptible to water shortage, have turned to interbasin transfers to increase their supply (Wollman and Bonen, 1971).

The cost of water from diversion of surface flows will almost certainly continue to rise because of the higher costs of storage, decreasing returns from storage, and increasing costs of building and operating transmission facilities.

The average storage costs for new reservoirs can be

TABLE 4. ALTERNATIVES FOR BALANCING SUPPLY AND DEMAND FOR MUNICIPAL WATER SUPPLY

Do Nothing	Increase Supply	Decrease Demand
1) Accept shortage Unplanned rationing	1) Increase system capacity Divert surface water Develop new groundwater supplies Conjunctively use ground and surface water 2) Improve efficiency Reduce evaporation Detect leaks 3) Modify weather 4) Desalinize water 5) Renovate wastewater Use for potable purposes Use for nonpotable purposes	1) Meters 2) Price elasticity Peak pricing, i.e. Peak summer pricing Marginal cost pricing 3) Restrictions 4) Educational campaign emphasizing water use conservation 5) Technological innovations and application, e.g. changes from water cooling to air cooling

expected to rise since most sites with the greatest potential for storage, and consequent lower costs per unit of storage, are already in use. Size is critical in calculating capital investment: dams impounding 10 million acre-feet or more cost on the average $26 per acre-foot of storage, whereas those storing less than 20,000 acre-feet cost an average of $186 per acre-foot of storage (Wollman and Bonen, 1971). Furthermore, storage costs are increasing because, as data collected over the last two decades indicate, the cost of undeveloped land is rising.

As the amount of storage is increased for any stream, a decreasing yield is available from any further increase in storage. As a result of providing increasing levels of yield in critical water areas of the country, many streams are approaching maximum levels of storage; any additional increase in storage would increase evaporation thereby reducing net flow. As previously noted, the Colorado River, the Rio Grande, and the Upper Missouri have all exceeded the point of maximum useful development. If the costs of providing storage are constant, the decreasing yield for each new unit of storage causes the resulting flows to be more costly.

In addition, as was noted earlier, cities are transporting water from increasingly remote areas. Any increase in distance between the source of supply and the point of use raises the cost of water transmission. Some areas of the country which have captured the total available local supply, now depend upon interbasin transfers for more water. If transmountain diversions are planned, they will require expensive tunnels and high energy inputs. As part of the increasing cost of diversion, transmission losses can become a major factor in the cost of water. The Fryingpan-Arkansas Project calculates a seven percent loss of water for every hundred miles of transmission (Southern Water Conservation District, n.d.).

Develop New Groundwater Supplies. Groundwater provides twenty-five percent of urban water supplies but is extensively used to supplement surface water sources. Even though it rarely serves as the sole source of supply of some major cities, more than half of the population served by municipal systems depend partly on groundwater. It is an important resource because an estimated thirty-five times the mean annual streamflow is available in aquifers. We will consider then in more detail the implications of having a source of supply consisting of both surface and groundwater.

Groundwater is usually found and exploited near the point of use and does not require the large capital investments of surface water supply systems for storage and transmission, nor are there any problems of evaporation. On the other hand, groundwater nearly always needs to be pumped, sometimes from considerable depths, and this requires substantial amounts of energy.

The long-term yield of groundwater sources is equal to the average rate of replenishment. Many cities are exceeding the replenishment rate and as a result the groundwater levels are declining. For those cities located along the ocean, salt water can intrude the aquifer sometimes destroying its usefulness as a source of water supply. Land subsidence is another result of overexploiting an aquifer. Subsidence occurs as the level of water in the aquifer declines and the weight of the overlying earth compresses the porous aquifer material. The ground surface subsides, and as in the area of Houston, Texas has made lakes of previously inhabited areas of the city.

Additional concerns of groundwater users grow out of practices such as salting roads in the winter to control ice, waste disposal, and excessive use of fertilizers. These materials may eventually enter the groundwater and degrade its quality over the long term. Such effects may be irreversible because unlike surface supplies, there is usually no way to flush out contaminants from the groundwater.

In general, groundwater resources have occupied the attention of the federal government less than surface water resources. Activities carried out hundreds of feet below the earth's surface may not have the perceptible

influences either on ecological cycles or on human amenity as those occurring on or above the surface. Nevertheless, the implications of activities affecting groundwater are profound. Although groundwater pollution may be irreversible, there are no laws governing its pollution equivalent to those governing surface water sources. Whereas overpumping may permanently destroy some aquifers there are no restrictions against excess use. Were those cities which depend on groundwater as a supplementary souce of supply unable to use groundwater, the results would be more serious than losing a portion of the surface supply because conjunctive use of ground and surface water sources which we will examine next has become a particularly desirable resource management strategy.

Conjunctively Use Ground and Surface Water. In many places, it has been possible to integrate ground and surface supplies into a single water supply system. Typically, aquifer capacity is used during periods when water levels in surface reservoirs are low. No matter how large the reservoir or how small the pumping capacity, integrated operation provides a larger sustained yield than separate operations. In conjunctive use the assured storage capacity of an aquifer may be used to reduce the uncertainty of surface supplies (Gert *et al.*, 1974:2–3):

> The basic attractiveness of integrated ground and surface water use resides in the characteristic differences between streams and aquifers as souces of water supplies. Through judicious co-ordination of these resources the strength of each overcomes the weaknesses of both. The abundant, but fluctuating surface water versus the lower (quantity) but steady (assured) delivery of ground water . . . are all factors to be considered in integrated use.

Integrated use provides an opportunity that most municipal systems combining surface and groundwater have not exploited fully.

Improve Efficiency

An alternative to developing groundwater and surface supplies is to increase the efficiency of those already developed. Other alternatives include decreasing evaporation from reservoirs and losses from distribution systems.

Reduce Evaporation. Evaporation of water is a function of a number of variables including water temperature, incident solar energy, air temperature, relative humidity, and wind speed. It has been calculated that losses resulting from evaporation range up to 100 inches per year in some extremely arid portions of the West (Meyer, 1942). Although the average loss is significantly less, evaporative losses can affect the net amount of water available from storage, especially for large, shallow reservoirs. Water quality is also affected because evaporation concentrates the dissolved solids in the remaining water.

One proposal for reducing the loss from evaporation has been to spread monomolecular films on water surfaces. An evaluation of the effectiveness of such films has shown that small organisms may destroy them, even moderate wind speeds may disperse them. They also tend to raise water temperature, which in turn promotes evaporation. Although the idea is attractive, monomolecular films have, as yet, not proved effective (National Science Foundation, 1968).

An interesting method of decreasing evaporation is to transfer surface water to groundwater strage. Lubbock, Texas employs such a system which uses surface and groundwater sources for urban supply during the summer. In the winter when total demand is less than available surface supply, the excess surface water is stored in the aquifer to be pumped up again during the next summer period.

Evaporation losses can be substantial in some western systems that use open supply canals to transfer water across extensive distances. One Colorado water conservancy district calculated the amount of loss at seven percent for each hundred miles of transmission.

Detect Leaks. In many municipalities, loss of water from the distribution system is significant (Table 5). Some systems cannot account for over forty percent of the water produced. Much of such water lost is through leakage. Stopping leakage can often be an alternative to new source development. Most water companies have ongoing leak detection programs. As the cost of developing alternative sources of water increases, there will be more incentive to find and repair the leaks.

Although losses occur both before and after the water has been treated and chlorinated for distribution, loss of the treated water is a more serious problem. Where this occurs not only is the value of the raw water lost but the cost of treating and pumping the water is also wasted. Where the water treatment plant in a system is at full capacity, leak repair may be a substitute for new construction when the system needs increased capacity.

TABLE 5. FREQUENCY DISTRIBUTION OF UNACCOUNTED-FOR WATER IN CITIES

Unaccounted-for water (% of production)	No. of Cities
5.0	130
5.0 – 9.9	52
10.0 – 14.9	72
15.0 – 19.9	55
20.0 – 24.9	33
25.0 – 24.9	17
30.0 – 39.9	13
40.0 or more	7
Total	379

Source: Seidel and Baumann, 1957: 1535.

Modify Weather

Weather modification offers a low cost opportunity to augment water supplies during periods of drought. The results have been highly variable and it is difficult

to assess whether there is considerable potential to augment supplies. For the cost of an airplane and some relatively low cost equipment, municipal systems can try to increase rainfall and runoff in their watershed. The technique is simple; moisture laden clouds are "seeded" with a substance which causes the minute droplets to aggregate, get heavier, and finally to fall as rain.

Since the process requires clouds which are often not present during periods of drought, some rainfall augmentation programs operate during the winter months when there is more cloud cover. This increases the winter snow pack in the mountains which then melts and runs off during the spring. A major difficulty has been to assess whether or not cloud seeding has caused increased precipitation. If rain or snow occurs after cloud seeding, would it have happened without interference? Statistical studies are still assessing the potential. One early report found that cloud seeding techniques have been observed to increase average precipitation from five to twenty percent under appropriate conditions (Malone, 1968).

One problem involved with increasing precipitation is the potential for legal suits based on causing unwanted effects. If a cloud seeding experiment in progress ends with precipitation that causes flooding, is the person responsible for the cloud seeding responsible for the deaths and property loss?

Rain making is not a dependable process and there are problems in using the technology. White and Haas (1975:383) made a careful assessment and concluded that:

> . . . the relative effectiveness of cloud seeding in various climatic locations under differing weather conditions is quite uncertain . . . and . . . knowledge of cloud seeding technology for precipitation enhancement in the arid Southwest is even less certain, and much more research is needed before operational programs become practical.

Desalinize Water

Desalinization is a process whereby sea water or brackish water can be converted to potable water suitable for municipal use. It is a technologically feasible but generally uneconomical source of municipal water. So far its use has been confined to small-scale operations where other sources are unavailable or prohibitively expensive. Desalinized water serves part of the Virgin Islands where conventional ground and surface water sources are limited and desalting was instituted to supplement the limited natural supply. Desalinization may be a supplement for some urban water supply systems depending upon the range and nature of other alternatives. Depending upon the size of the treatment plant, the costs of desalinization to produce potable water may be competitive with importing fresh water. The unit cost of the desalting decreases significantly as the scale of operation increases (Miller, 1972).

Renovate Wastewater

Water reuse is the final alternative for supplementing supply. It is a potentially attractive method for using largely untapped sources of supply close to the city. In contrast to the other alternatives, however, there are questions of the safety and acceptability of the process in addition to the usual question of economic efficiency. For this reason the section on reuse will review some of the evidence on safety, acceptability, and economic efficiency of the process.

The concept of water reuse is simple, it is the process of collecting wastewater and treating it for an additional use. It is not a new concept. It is a fact of urban water supply. During low flow periods Koenig (1966) found that up to eighteen percent of some sources of municipal water supply were wastewater. In the intervening period, the fractions of reuse could have risen only as municipal withdrawals and therefore sewage discharges have increased.

The inadvertent reuse represented by the withdrawal and subsequent use of wastewater by municipal systems has not been questioned, but planned reuse as a potable supplement to municipal supply has not been adopted—although federal legislation dealing with it has long been recognized by such groups as the Senate Select Committee on National Water Resources in the early 1960's. In 1965, the Water Resource Planning Act required that reuse be considered one of the alternative methods of meeting future demand for water, as did the National Water Commission Act of 1968. In the final report, the U.S. National Water Commission (1973) recommended that the reuse of renovated wastewater should occupy a prominent spot in future planning for overall water resources use. The Clean Water Act of 1977 provides that the federal government pay the complete cost of evaluating the technical feasibility of reuse.

Although inadvertent reuse continues to increase and planned reuse of municipal effluent for irrigation is reported by over 325 communities in the United States, few are presently reusing water for industrial or domestic purposes, where its use could replace potable water (Table 6).

There are some innovative developments in reuse. Denver, Colorado has a 1 mgd (million gallons per day) demonstration plant under construction and has plans to move to full scale reuse of treated sewage for potable supply. Orange County, California has completed a 15 mgd wastewater reclamation plant, part of Water Factory 21, so designated because it purports to use 21st century technology. The balance of the "Water Factory" is a desalinization plant. The purpose is to treat sewage and blend this with desalinized sea water for groundwater injection to prevent salt water intrusion into the coastal aquifer (Argo, 1976). Also, the U.S. Army Corps of Engineers has launched the Potomac Estuary Water Treatment Plant to determine the feasibility of using the estuary as a supplemental source of water supply for Washington, D.C. Currently, a 1 mgd plant is under construction. Upon completion in 1979, the

TABLE 6. GEOGRAPHICAL DISTRIBUTION OF MUNICIPAL REUSE

State	Number of Municipalities Practicing Reuse				
	Irrigation	Industrial	Recreational	Domestic	Total
Texas	144	5	0	0	149
California	134	1	3	0	138
Arizona	28	2	0	1	31
New Mexico	10	0	0	0	10
Colorado	5	1	1	0	7
Nevada	4	2	0	0	6
Other	12	3	1	0	16
Total	337	14	5	1	357

Source: Schmidt, Kugelman, and Clements, 1975.

Corps of Engineers will gather data for two years to determine the effectiveness and reliability of building a larger scale treatment plant.

Public Health Factors. At present, there are no cities in the United States processing effluent for direct potable use. One of the only U.S. experiences in this area occurred from October 1956 to March 1957, when Chanute, Kansas treated and reused water to augment the municipal supply directly. Although the quality of the renovated water met the standards established by the U.S. Public Health Service (1962), the chemical composition deteriorated markedly, the water had a pale-yellow color, an unpleasant taste and odor, and foaming occurred when agitated (Metzler *et al.*, 1958). Prior to Chanute, in late 1939 and 1940, another community, Ottumwa, Iowa, also recycled renovated wastewater and no health problems were observed (Brown, 1940). Whereas there is no long-term reuse application in the United States, reuse has been used to supply drinking water in Windhoek, Namibia and the water produced meets all of the standards set by the World Health Organization (Cillie *et al.*, 1966, Stander, 1969).

Although promising, the conclusions reached from these few experiences should not lead to undue confidence about the effect of renovated wastewater on health. Bacteria and viruses appear to be controlled under proper filtration and chlorination. However, little information is available on the occurrence and distribution of heavy metals, such as chromium, mercury, lead, and of organochlorine compounds, such as carbon tetrachloride, DDT, aldrin, dieldrin, and chlordane, which are known to be potential carcinogens and which may be in the treated effluent.

The lack of definitive information on water quality and health should not preclude serious consideration of water reuse as a possible alternative in planning for municipal water supply. Similar problems exist for nearly all other alternative sources of municipal supply. In a survey of 969 communities, for example, only fifty percent of the communities produced drinking water that was acceptable under the recommended standards of the U.S. Public Health Service (1970). The point is simply stated: the answers to questions regarding health and water quality are unknown for both water reuse techniques as well as for the currently operating conventional water supply treatment technologies.

With the passage and implementation of the 1974 Safe Drinking Water Act, progress should be made towards improving the quality of our drinking water. In addition, with the completion of the Denver, Colorado water reuse project, the quality of the finished product will undoubtedly be significantly higher than the tap water presently available in most communities of the United States. As Dean noted as early as 1965 (p. 470):

> We can make a better quality of water by treating sewage than is available in many of our cities. Controlled treatment of a known hazardous raw material can produce a safer product than routine treatment of a deteriorating source. Viruses can be removed from heavily polluted water by suitable treatment and the cost is not unreasonable.

The entire question of health is circumvented in those situations where water can be reused for purposes other than ingestion, e.g. industrial cooling, irrigation, and recreation. Indeed, it is these noningestive uses where reuse will most likely be adopted. However, communities might forego savings if they do not consider water reuse as a potential source for potable water.

Public Acceptance. Although renovated wastewater may be relatively safe to drink, a second and equally important question deals with public acceptance, not only by the consumers, but also by the politicians, management personnel, public health officials, and consulting engineers. In essence, no program using renovated wastewater can be implemented without their acceptance.

Recalling the fluoridation debates and being aware of the heightened public participation in public policy issues of the present day, water resource managers have paid particular attention to the public's acceptance of recycled wastewater. In Baumann's unpublished survey of 300 municipal water managers in the United States in 1969, anticipated rejection by the public was the

most common reason cited by the fifty percent who opposed wastewater reuse. Similarly, Johnson (1971: 92) found that "it would appear that water managers know very little of consumer responses concerning renovated wastewater but generally consider the public would not accept it." On the other hand, in a review of the literature, Baumann and Kasperson (1974:673–674) concluded that "there is little evidence to support the widespread conviction among those charged with proposing solutions to the nation's water supply problems that public opposition constitutes the most important obstacle to the adoption of wastewater reuse systems."

Moreover, there is evidence that the public will accept renovated wastewater for potable use provided they are aware of the *technological characteristics* of water treatment. Based upon survey data in five communities, Sims and Baumann (1974) suggest that what the consumers know and feel about drinking renovated wastewater is related to their general level of education and knowledge about water treatment, and it is not related to unconscious fears of specific dangers such as contamination, nor to attitudes about nature, technology, aesthetics, authority, progress, or destiny.

Prior to preparing plans for a reuse plant in Denver, Colorado 500 people were surveyed to find out their attitudes toward reuse. The experience supports other data on consumer acceptance. The initial response to the concept of recycling renovated wastewater was primarily negative. However, as the respondents received additional information about the implications of water reuse planning, the rate of public acceptance increased until eighty-five percent of the respondents expressed a willingness to drink renovated wastewater (Heaton *et al.*, 1974).

A key obstacle in considering and adopting recycled renovated wastewater in municipal water supply planning may lie not so much in the mind of the consumer as in the perceptions of consulting engineers and public health officials—two groups that strongly influence community decision-making for planning municipal water supplies.

Sims and Baumann (1976:9) interviewed ninety-eight consulting engineers (thirty-three firms) and twenty-two state public health officials (from nine states) for a study on the practicability of a community program using renovated wastewater. According to their findings it is public health officials who " . . . hold the more negative position—they begin by not liking the idea, then raise many and major objections to it, and in the end, find their reflection has strengthened their antagonism. Consulting engineers . . . begin with a far more favorable attitude, raise fewer objections and conclude with a perfectly even-split between endorsement and rejection." Hence, professional biases may serve as a greater obstacle to questions of reuse than public opinion.

Economic Feasibility. If the engineers recommend and the public will adopt reuse, is it an efficient method of supplying water for a municipal system? To make that judgment requires examining what happens to sewage, the source of water for reuse.

The costs of providing reused water are declining primarily because of the required upgrading of effluent discharged by municipal systems. Under the 1972 Federal Water Pollution Control Act Amendments, the federal government established standards that mandate secondary treatment of all municipal sewage and, in certain instances of special need, additional treatment to the advanced level. Whether the sewage requires secondary or advanced treatment, the additional costs involved in further treatment before distribution and reuse may not be substantially higher than the costs for treating water from other sources, and where reuse is supplied for nonpotable purposes no further treatment may be required.

Although reuse of water for return to potable water supply systems has been shown to be feasible, most currently planned reuse of water is for nonpotable purposes, supplied directly from the treatment plant to the user. This includes most of the present irrigation, industrial, and recreational uses. Any scrutiny of the efficient use of nonpotable reuse must start with the concept of an integrated system designed so that either treated effluent or potable water could be furnished to users. This concept allows the water managers to decide whether to produce and distribute treated effluent, or to use only the normal potable supply for all uses. System integration thus eliminates unnecessary costs in producing and distributing effluent during periods when unused capacity exists from other sources.

The Role of Reuse. The concept of system integration relies on the general relationship between reuse and storage of flows, and provides a guide to the optimal use of treated effluent. According to this relationship, reuse systems cost less to build, but are more expensive to operate than are systems designed to divert and store flows. This suggests that reuse systems will operate only when water from storage is unavailable to meet the demands. In this way, reuse would function most efficiently as a source of peak supply whereas storage, with its low operating costs, would provide the necessary, continuous capacity. It should be noted, however, that systems that do not consider treated effluent as an acceptable source of potable supply will have to construct a separate distribution system for nonpotable water.

Reliance on reuse as a standby source not affected by periods of low flow can increase system yield and provide planning flexibility in three major ways: (1) to achieve the high levels of assurance required in municipal systems; (2) to mobilize any oversupply in the system; and (3) to shorten the planning cycle.

The yield of a water supply system, based on storage of flows, is usually expressed as a quantity of water available or assured ninety-five percent (or more) of the time. To achieve this level of assurance, some storage must be provided that will be required less than five percent of the time. Because yield increases as assurance declines (Löf and Hardison, 1966), the yields from a system could be increased by allowing the levels of assurance in a system to be relaxed. Reuse could furnish the additional water necessary to maintain the desired level of assurance.

Because many engineers find a potential shortage for less than five percent of the time unacceptable, engineering and reference handbooks urge using conservative calculations for planning municipal water supply systems. Social scientists, on the other hand, assert that yields are often, if not always, understated. Furthermore, cities experiencing periods of drought indicate that water rationing has not caused undue hardship. Renovation and reuse can play a constructive role in this ongoing debate on levels of assurance. Thus, reliance on reuse as a standby source would allow using present facilities until the response of the physical system to the demands placed on it can be evaluated pragmatically, thereby replacing the engineering estimates of yield.

The long time required to develop new water sources requires long-term estimates of future demands for water. In the past, because the rapid growth of water use consumed any excess capacity, there was little concern if the future demand was overstated and if subsequent projects based on this inflated demand resulted in temporary oversupply. There is evidence, however, that this rapid growth in demand has slowed. Furthermore, certain factors, such as low birth rates and single family house replacement with apartments and cluster homes having smaller lawn areas per living unit, indicate that the present slowdown will continue. As a result, excess capacity added now under lower rates of growth will be used more slowly, with a consequent investment in idle capacity for a longer period. Utilization of reuse thus becomes significant since it allows for the pragmatic evaluation of change in demand, and helps reduce reliance on long-term predictions in planning for water supply systems.

Alternatives That Decrease Demand

Proposals to make managing water demand integral to planning procedures have predictably met with considerable suspicion, not only by the public, but by those professionals involved in the planning process. This is understandable because conscious decisions about controlling water demand have important consequences for the growth and development patterns of whole sectors of the economy. On account of complex political implications, most measures to control demand for water have been associated with responding to emergencies and have usually been imposed temporarily.

Despite traditional opposition to policies aimed at controlling demand, the growing problems involved in increasing supply are forcing those responsible for municipal water management to examine demand-related measures. These measures, as discussed in the following section, include metering, pricing policy, and restrictions on use. Such measures may be useful not only in reducing overall consumption but also in redistributing patterns of peak system load.

Metering

The introduction of metering into a water system had a major effect on the consumption of residential and commercial water. For example, with only twenty-five percent of New York City water users being metered, it has been estimated that complete metering could reduce consumption by 125 mgd, or about ten percent of average daily use (D'Angelo, 1964). However, since most public and private systems in the United States are metered, the potential of this particular alternative for increasing efficiency in water use is relatively limited.

The effectiveness of metering in controlling water demand is clear. A study of Boulder, Colorado showed that "per capita consumption dropped about forty percent over the period from 1960, when Boulder was only five percent metered, to 1965 when it was fully metered" (Hanke and Flack, 1968:1365). The effect of complete metering gave Boulder the capability to serve an additional 11,000 persons with the same water supply.

Although the forty percent drop in Boulder may be unusually high, the literature reveals a consistent pattern of reduced water consumption after adoption of metering. In 1958, Kingston, New York initiated a universal meter installation program. By 1963, metering covered ninety-eight percent of the system and average water use had decreased more than twenty percent. When Philadelphia completed universal metering from 1955 to 1960, the demand among the previously unmetered customers was calculated to have dropped by at least twenty-eight percent (Cloonan, 1965).

The effect of metering on water demand can be demonstrated in a comparison made between metered areas and flat-rate areas. In a study, the average water use was 458 gallons per day per dwelling unit in metered areas as compared to an average of 692 gallons per day in flat-rate areas. The difference was largely the result of a reduction in lawn-sprinkling (Howe and Linaweaver, 1965).

The effect of metering in lowering demand for water appears to have a long-term effect. As meters were installed over a thirty-year period in the Boston Metropolitan District Commission, the demand for water declined from 130 gallons per capita per day to approximately 100 gallons per capita per day (Russell *et al.*, 1970).

Pricing

Pricing of water can be a useful management tool. As was pointed out in the discussion of metering, consumers respond to increased price by decreasing use; thus, pricing can be used to decrease or shift demand. Rate structures inevitably favor, explicitly or implicitly, certain uses or users. Water rates involve issues of social equity as well as system efficiency. This may help to explain the resistance frequently encountered by proposals to modify rate structures.

The price of water varies enormously among municipalities. In a study of 485 utilities in Illinois, Afifi (1969) noted that the price ranged from zero to $10.95 for 5,000 gallons per month. The average cost of water for domestic use varied from 53.6¢ to 93.6¢ per 1,000 gallons in 1975 (Table 7). Gottlieb (1963) observed a

TABLE 7. AVERAGE RESIDENTIAL WATER RATES 1975*

Population Range Of Water Supply System	Average Rate (¢/1000 gallons)
Over 1 million	53.6
100,000–999,999	65.2
10,000– 99,999	71.7
5,000– 9,999	79.2
2,500– 4,999	93.6
1,000– 2,499	85.2
500– 999	78.5
100– 499	89.0
25– 99	73.5

*Based on equivalent of approximately 90 gallons per capita per day for a family of three with an annual usage of 100,000 gallons per year. Source: U.S. Environmental Protection Agency, Office of Water Supply, 1977: vi–14.

wide variation in water rates among communities in Kansas and identified five factors that might account for such differences: the effect of economies of scale, the differential costs of water drawn from different sources, the differential costs in the type of treatment, the variation in the nature of the distribution systems, and the effect of differential use of utility taxation.

There are basically five types of water-pricing policies: (1) declining block-rate or promotional pricing; (2) constant rate (per unit) schedules; (3) flat-rate or fixed monthly charge; (4) summer differential rate; and (5) incremental block pricing. The declining block rate, often described as "promotional" pricing, is the most common schedule now in use. It is estimated that ninety-four percent of municipalities rely on this rate (Gysi and Loucks, 1971). Usually there is a minimum charge followed by lower rates as the volume of water purchased increases. The next most widely used rate is the constant rate schedule that bills the consumer at a constant price per unit of water regardless of the quantity used. A minimum charge may also be required. Flat-rate schedules, once a common method of charging for water, are relatively rare. In a survey of 123 water utilities, only 3 cities used a flat-rate schedule. Ironically two of these, Aurora, Colorado, and Reno, Nevada, are located in the arid western states (Gysi and Loucks, 1971). Flat-rate charges are, of course, characteristic of unmetered systems.

Summer differential rates may be used in conjunction with other rate structures. Unlike flat, constant, or declining block rates; such structures represent a conscious attempt to modify demand. In some places during the summer months the demand for water results in pressure loss or reduced reserves; consequently, higher rates are imposed during this period in order to lessen peak demands. The practice of summer differential rates is not widespread but does occur in the subhumid areas of the United States.

Incremental block pricing is a relatively new concept in pricing that has not gained widespread acceptance. Water rates increase as the amount of water purchased increases; thus, incremental block pricing is a reversal of the declining block-rate schedule. It is principally intended to encourage water conservation and also provides lower unit rates to low-volume water users, which include low-income groups. The Washington Suburban Sanitary Commission (WSSC), which serves part of the suburban area of Washington, D.C., has inaugurated an incremental block-rate pricing policy. The new increasing rate structure is advertised as a method of encouraging water conservation. In this rate structure the price of 1,000 gallons of water rises from $.81 to $2.36 (including sewer use charges) as use *increases* (Table 8).

The American Water Works Association noted in 1958 that in practice, the pricing policies of most systems are widely at variance with a principle of economic efficiency that would price water to each user at the cost of providing the water. Such a pricing policy is marginal cost pricing. In this method, the cost of supplying an *additional* unit of water determines the price of water. Traditionally, the price of water has been determined by dividing the total system costs by the amount of water delivered, a procedure known as average cost pricing.

An examination of average cost pricing from the viewpoint of economic theory has led to severe criticism of conventional pricing on the grounds that it encourages overinvestment in system capacity. The price of water from the newest and often the most ex-

TABLE 8. NEW WSSC WATER/SEWER RATE SCHEDULE*

Average Daily Consumption By Customer Unit During Billing Period (Gallons Per Day)	Rate Schedule Established Per 1,000 Gallons Of Total Consumption		Average Daily Consumption By Customer Unit During Billing Period (Gallons Per Day)	Rate Schedule Established Per 1,000 Gallons Of Total Consumption	
	Water Consumption	Sewer Usage		Water Consumption	Sewer Usage
10	$.36	$.45	510	$.97	$1.22
100	.48	.66	600	.99	1.24
200	.70	.90	700	.99	1.25
300	.85	1.06	800	1.01	1.26
400	.94	1.16	900	1.03	1.27
500	.97	1.21	1000	1.05	1.31

*Effective January 1, 1978, To Be Applied on Customer Unit's First Bill Reflecting Metered Consumption Wholly Recorded During Calendar Year 1978. Source: Washington Suburban Sanitary Commission, 1978.

pensive increases to the system is averaged in with the price of older lower cost additions to supply. Average cost pricing thus contains a bias in favor of system expansion—a residual bias left over from the days when water was regarded as a free good.

Commenting that water can no longer be considered a free good, Hanke and Flack (1968:1360) note a shift has occurred from the "requirements approach to water, that is, viewing water use in terms of an absolute amount of water demanded by a projected population for a municipality, to viewing demands of water as the willingness of consumers to pay." Many economists have maintained that a shift to marginal cost pricing would significantly affect the demand for water, especially in the commercial and residential sectors. According to Gysi and Loucks (1971:1372), "Marginal cost pricing policy could save a much larger percentage than any policy of meeting demands at all times by always increasing capacity in advance of demands." Moreover, Riordan's (1971) study concluded that multistage marginal cost pricing might result in a ten to twenty percent saving over average cost pricing policy.

It has also been proposed that utilities abandon the traditional fixed rate schedules of the past, and allow prices to fluctuate with short-term marginal costs because any cost or savings involved in system operation or expansion, or from fluctuations of supplies, would be passed directly to the customer (Hirschleifer, De Haven and Milliman, 1960). Such fluctuating rates would involve only minor administrative expense, but could be expected to meet with opposition from both the public and professionals in the field. A further problem in implementing marginal cost pricing involves the accurate determination of the marginal cost and of the cost increments to be used.

In the context of both the increasing costs of water and waste treatment and the increasingly serious legal and environmental conflicts involved in system expansion, pricing policies will undoubtedly be considered as a means of not only adjusting revenues but of increasing or decreasing average and maximum day demands (Howe and Linaweaver, 1967). The effectiveness of increased water rates in modifying demands is well documented. Nonetheless, as already indicated, the reallocation of water implied by this method is not simply a matter of system efficiency; for example, altering the pricing structure may affect the nature or the rate of economic development. There are also significant social considerations involved in that customers who reside in high-density areas closest to the water system's load center subsidize those who reside in low-density areas farthest from load centers (Hanke, 1974). This is the result of the costs of extra piping and pumping required to serve remote areas.

Pricing policies for water should become more important management tools. They are unique since they are adjustable to meet wide goals and can be implemented without great capital outlay or significantly increased operating costs.

Restrictions on Use

Although restrictions and rationing of agricultural water have been traditionally practiced in the more arid regions of the country, such measures have never been popular. As a policy tool for municipal planning, water system managers regard restrictions on water use as a last resort in coping with severe system stress or the threat of serious water shortage. A variety of restrictions have been imposed in different parts of the country, usually in response to prolonged drought.

One great advantage of the restriction strategy is its flexibility. Restrictions may be voluntarily or legally imposed; they may be based on hours of use or types of activity; they may be confined to peak demand periods; or they may be general in nature. One drawback to voluntary restrictions is that their effectiveness appears to be severely limited unless the public is convinced that a crisis situation exists.

From a review of the literature, it appears that communities faced with potential water shortages are quick to formulate and impose programs of water use restrictions. For example, at least sixty-four of the seventy-five communities in Illinois that suffered shortage at some time during the drought of 1952–1955 enacted restrictions on use (Hudson and Roberts, 1955). In a study of forty-eight communities in Massachusetts during the drought of the early 1960's, thirty-four adopted restrictions. The restrictions were most often imposed on domestic users with the public and industrial sectors having fewer restrictions (Russell, Arey, and Kates, 1970) (See table 2).

As a matter of policy, it is possible that publicizing the cost implications of system failure would increase public tolerance for and cooperation with restrictions. One rational way of promoting customer acceptance of water use restrictions and of the idea of a planned failure rate for a municipal water supply would be to publish, in advance, lists of planned restrictions to be applied under various threatened levels of shortage. For example, the system's customers would know that in the face of a possible ten percent shortage, all outside water use (sprinkling, car-washing, etc.) would be forbidden and no nonrecirculating air conditioners would be permitted to operate. If the potential shortage were fifteen percent, swimming pools could not be refilled. A thirty percent shortage might involve slowdowns or shutdowns of local water-using industries.

It is difficult to define the degree to which the public will accept restrictions, and it is probably subject to some modification through education campaigns. However, the imposition of restrictions has been shown to be an effective management tool for relatively short-term problems (Russell, Arey and Kates, 1970).

V. MANAGEMENT OF WASTEWATER

Wastewater is an inevitable accompaniment to urban water use. The returned water collected as sewage usually amounts to nearly sixty-five percent of the volume of water supply.

In the past, sewage treatment was never considered a part of the water supply problem of cities and in most cities today the same attitude prevails. Consulting firms who advise cities on water problems have "clean" water and "dirty" water specialists who deal with supply or waste treatment. Often cities employ different firms to advise on water supply and waste treatment. However, the problems of water supply and waste treatment are inevitably linked since sixty to eighty percent of all water supplied ends up as sewage. Unless we consider sewage treatment as part of the water supply problem, we may underestimate the full costs of increased water use and forego the potential for using treated effluent to displace or delay new source development.

Legislative History of Sewage Treatment

Public Law 95–217, the Federal Water Pollution Control Amendments, is the latest legislation reflecting a shift from local to state to federal control of sewage treatment. The first legislation relating to municipal control of sewage dates back to 1647 when legislation was enacted in Boston which made it "unlawful for any person to cast any dung . . . or anything [illegible] up the Cove or annoy the neighbors under a penalty of 40 shillings" (Rowland and Heid, 1976). Other cities faced with the problems of waste disposal provided legislation requiring and controlling the building and operation of sewers. The State role in pollution control started in Massachusetts with the formation of a State Board of Health which in 1886 was given control over the quality of inland waters and was charged with investigating methods of protecting their quality. New York followed Massachusetts and created a State Board of Public Health in 1870 which immediately began to deal with the problem of handling human wastes. The board recommended a dual sewage system, one for wastewater and a second for storm runoff. This period marked the beginning of sewage control by State Boards of Health. Other states joined [illegible] the legal control of sewage. Although the legal control was vested in the agencies which built collection lines for sewage, the state health agencies did little to treat the sewage which continued to increase in volume. The objective was to control sources of supply, not to ameliorate the effects of waste discharge. Except for a brief flurry of construction of sewage plants during the 1930's, under programs designed to put the nation to work, waste treatment received a low priority in local government budgets.

In 1948, with the passage of the Water Pollution Control Act the federal government became involved in sewage treatment. The act provided financial assistance to states and interstate agencies to plan for pollution control facilities and provided loans for their construction. The loan program, however, was not funded. Congress amended the act in 1952 and 1956. The revised act allocated federal money for sewage treatment under the control of water quality agencies responsible for setting stream standards. The federal grants provided a maximum of $250,000 and covered thirty percent of the cost of construction. The 1966 Water Pollution Control Act Amendments increased the federal share of projects to fifty percent if the state agreed to pay twenty-five percent and if stream standards had been established for the streams receiving the discharged effluent. The federal share could increase to fifty-five percent if metropolitan areas established comprehensive water pollution control plans.

Evaluating The Current Program

The newest law governing comprehensive water pollution control plans is set forth in the 1972 amendment to the Water Pollution Control Act (P. L. 92–500), which was designed "to restore and maintain the chemical, physical, and biological integrity of the nation's waters." The law provides a schedule of increasingly demanding goals for the quality of effluent discharged to streams.

The first goal which had a deadline of July 1, 1977, was for municipalities to treat sewage by the best practicable technology. By July 1, 1983, the law will require the use of the best available technology economically achievable, and finally the goal is "that discharge of pollutants into navigable waters be eliminated by July 1, 1985." The 1977 goal was not met. Today, only one-third of the municipal systems can meet the standards required by the law. Later we will discuss further the present status of municipal treatment under the topic of meeting the goals of P.L. 92–500.

The Environmental Protection Agency (EPA) has the responsibility of setting the standards for effluent discharge that are appropriate to meet the goals of the act. The EPA defines the level of treatment to meet the 1977 goals as secondary treatment and specifies maximum allowable bacteria, decomposable organic material, and suspended solids. One standard was set for thirty-day periods with a less rigid requirement for a one-week period to allow for short-term fluctuations in treatment efficiency or pollutant load (*Federal Register*, 1973). The standards for the 1983 goals have not as yet been published, but 1983 draft standards provide more rigid requirements for decomposable wastes. By 1985, the goal of the law is to eliminate discharge of pollutants into navigable waters. There is considerable controversy over the meaning of this goal, since the technology to approach the level of treatment is not yet

available and a strict interpretation would make it impossible for communities to comply.

P.L. 92–500 calls for a statewide water quality management plan that would set priorities and schedules for each stream basin within the state and would establish a priority list of communities to receive federal funding for treatment plants. Section 208 of the law provided for area rather than community planning. Under the provisions of Section 208, local governments would relinquish control and would participate in a coordinated effort to plan for area-wide waste treatment facilities. The objective is to avoid building a large number of small plants which are more expensive both to build and operate.

Three questions are important in evaluating the appropriateness of the provisions of P.L. 92–500: 1) What is the effect of pollutants on water bodies? 2) How can the level of pollutants be controlled? and, 3) What would be the cost and the benefits of such a program? We will discuss how effective the law has been in achieving the stated goals in the final part of this chapter.

Public Law 95–217, which amended the provisions of P.L. 92–500 by extending the deadlines of July 1977 to as late as July 1983, also further encourages the search for alternative, energy-efficient methods of treating wastes. For those systems that treat wastes by nonstructural methods; e.g. land treatment, the federal government will pay up to eighty-five percent of the cost rather than the seventy-five percent for conventional plants.

Pollutants and Their Effects

Pollutants in municipal sewage can be classified into two groups. The first consists of degradable wastes that are chiefly complex organic compounds and chemical wastes readily decomposed into more stable forms. The second group of pollutants are the non-degradable wastes, stable chemical elements and compounds which include organic and inorganic materials such as pesticides and heavy metals. Non-degradable wastes may be diluted or removed but are not changed in form or weight during the treatment process.

Degradable Wastes

In the past, wastes of biological origin consisting of materials and waste products of plant and animal origin constituted the most serious problem. These wastes use oxygen in the process of decomposition. The amount of oxygen used is known as the biological oxygen demand (BOD). These complex organic compounds serve as a source of food for organisms and are converted in the process into more stable compounds. Under normal conditions the organisms involved are aerobic bacteria, which live in the presence of oxygen. The end products are more bacteria, carbon dioxide, nitrates, sulphates, and phosphates.

If no oxygen is present, the wastes serve as a food source for anaerobic bacteria, which can exist without oxygen. When anaerobic bacteria decompose wastes, the resultant products are methane, a combustible gas, and hydrogen sulfide.

Chemicals that combine with oxygen directly to form stable chemical compounds are another type of degradable waste. They require no biological activity, simply the presence of oxygen for the change to take place. These are classified as chemical oxygen demanding (COD) materials.

Non-Degradable Wastes

Other wastes that are now receiving more attention are the stable organic and inorganic chemical wastes. The organic wastes are often products of synthetic chemical processes for which there is at present no effective method of identification. Other non-degradable wastes, metals such as copper and lead, and the heavy metals, cadmium and mercury are present in wastewater from municipal systems with industries.

The Oxygen Sag Curve

When BOD and COD wastes are discharged to water bodies, they use the available oxygen dissolved in the water. All natural bodies of water with little or no pollutant load contain some dissolved oxygen. The amount is inversely related to the temperature. When water contains the maximum possible amount of dissolved oxygen (DO) it is said to be saturated. The saturation level of unpolluted water is 9.2 mg/l at 20°C.

Biological and chemical oxygen demanding wastes use the dissolved oxygen in the water in converting from unstable to stable compounds. As the oxygen levels decline from the level of saturation, additional oxygen from the air is dissolved. Both processes, oxygen depletion and reoxygenation, take place simultaneously; the greater the rate of depletion, the higher the rate of reoxygenation. The combination of both processes produces the typical oxygen sag curve which represents the change in oxygen levels of water when BOD and COD wastes are added (Figure 8).

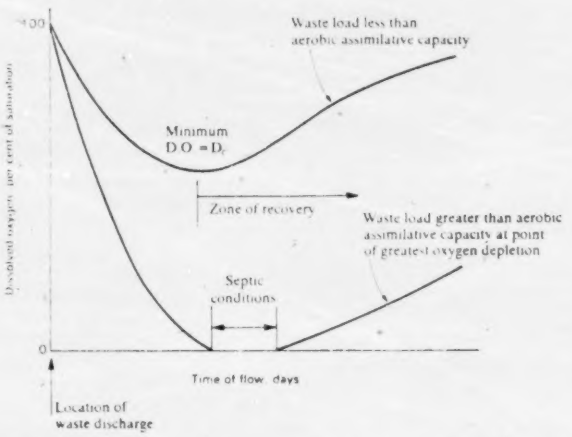
100
Waste load less than aerobic assimilative capacity
Minimum D.O. = D_c
Zone of recovery
Waste load greater than aerobic assimilative capacity at point of greatest oxygen depletion
Septic conditions
0
Time of flow, days
Location of waste discharge

Figure 8. Schematic primary oxygen sag curve for two different organic waste discharges. Source: Kneese and Bower, 1968: 21.

When the rate of oxygen depletion exceeds the rate of reoxygenation, and the total amount of oxygen dissolved in the water is used, the water is considered to be anaerobic, that is, without oxygen. Under these conditions, the BOD wastes are stabilized by anaerobic bacteria that produce different stable end products; the most important are methane, a gas that can be used as a fuel, and hydrogen sulfide that has an objectionable odor often compared to the smell of rotten eggs. The presence of hydrogen sulfide is an indication of anaerobic decomposition. Anaerobic bodies of water are said to be septic.

Effect of Dissolved Oxygen Levels

Whereas the presence or absence of dissolved oxygen control the type of decomposition of wastes, the level of oxygen is of primary importance in the ecological balance of the stream. Some valuable species of game fish such as trout and salmon, require high levels of dissolved oxygen, 6 parts per million (ppm), to survive and even higher levels to reproduce. Other fish such as bass require lower levels, but even these should have a minimum level of 4 ppm of dissolved oxygen (National Academy of Sciences, 1972).

The biological oxygen demand of waste material occurs over a variable period of time. The period depends upon the temperature of the water. The full decomposition of the wastes into stable compounds is not fully completed for a period of two months or longer at temperatures of 20°C or less.

Two stages can be identified. In the first stage, the carbonaceous material is decomposed into nitrogenous materials; in the second stage the nitrogenous materials are further modified, a process that requires more dissolved oxygen. At 20°C, the first stage of the process extends for approximately ten days—the period of most rapid dissolved-oxygen depletion. During this period, as much oxygen is required as in the next sixty days.

To provide a standard measure of oxygen requirement, a five-day bio-chemical oxygen demand (BOD) test was established. It is a laboratory test that measures the oxygen use of a liter of wastewater at 20°C in five days. The amount of BOD is often expressed in population equivalents (PE), a measure of the amount of waste produced by one person daily. One PE is defined as .17 pounds of five-day BOD material.

Another class of wastes, the chemical oxygen demanding (COD) substances, also depletes the oxygen level of streams. These substances use the dissolved oxygen in the stream directly rather than through the mediation of anaerobic bacteria. The effect on dissolved oxygen, however, is the same.

Non-Degradable Wastes

Although the non-degradable wastes do not affect levels of dissolved oxygen directly they can have serious consequences on the aquatic environment and on the ability of sewage treatment plants that rely on biological activity to function effectively. The wastes can stop the biological activity on which the plant depends and in addition some of the waste discharges can be poisonous to some or all of the stream organisms. If such a discharge occurs, there may be extensive fish kills. In extreme conditions the water may become an ecological desert both because of the poisonous nature of the discharge and of the increased BOD loading on the stream as a result of the nonfunctioning of the treatment plant. Since the water downstream may serve as a source of water supply to another community, the presence of the non-degradable wastes may be undesirable because of unpleasant tastes and odors, or, in some cases, hazardous to the health of the consumers.

The effects of non-degradable wastes on bodies of water in which they are discharged vary depending on the type of waste and the concentration. If the level of dissolved solids rises, the water becomes less valuable for subsequent use, either for irrigation or for water supply. If chemicals that are toxic to aquatic life are discharged, there may be partial or complete fish kills. Acids or alkalis may change the stream ecology. Phenols and chlorinated hydrocarbons are suspected of causing cancer even in low concentrations and therefore are undesirable in water that will be reused for a source of supply downstream. Synthetic dyes can affect the aesthetics and ecology of streams and lakes.

Non-degradable wastes can, in fact, affect the complete range of water uses except for transportation, including the subsequent use for recreation, aesthetics, public water supply, agriculture, and industry. They can also modify the fresh water and marine habitat as well as damage any wildlife coming in contact with the water.

Wastewater Treatment

Wastewater treatment is the process or series of processes by which sewage, the return flow from water used by residential, commercial, industrial, and other users, is treated to remove or to modify some, or all of the elements added to the water in the course of its use to provide a satisfactory effluent. To do this the wastes are subjected to any or all three types of treatment processes: physical, biological, and chemical. We usually refer to the stages of treatment as primary, secondary, and tertiary. In the past, each stage was related to a specific type of treatment: primary treatment was always a physical process; secondary treatment was reduction of BOD and COD by oxygenation in a biological environment; and, tertiary treatment was a combination of physical and chemical processes that would provide control or elimination of specific pollutants from the effluent.

This has changed. Some treatment plants are now totally physical and chemical with no biological component. Other treatment processes are not plants at all but depend upon treatment by storing raw wastewater in lagoons, allowing solids to settle out, and spraying the clarified wastewater on cropland.

The possibilities for treating sewage at primary, secondary and tertiary levels are extensive but we will discuss only the most common processes.

Primary Treatment

Primary treatment is the first step in treating the incoming sewage or influent. Several processes screen out successively smaller solids. Some are removed by screening, while other particles are allowed to settle out by impounding the sewage in settling basins. Floating solid material is skimmed from the top of the sewage (influent). Finally, the influent can be filtered through media such as sand or anthracite.

Whereas primary treatment always involves some physical screening, the chemical additives can achieve sedimentation or flotation to aid in coagulating the solids suspended in the wastewater that will then more readily drop out of solution. These processes, straining, screening, sedimentation, and skimming, can remove up to seventy percent of the suspended solids, or forty percent of the BOD and thirty-five percent of the COD of the sewage.

Secondary Treatment

Secondary treatment by biological and physical chemical processes provides further reduction in the BOD and COD loads of the wastewater. Both methods can provide up to ninety percent reduction in oxygen demand from the original sewage.

The biological processes are designed to bring bacteria in contact with sewage under conditions where the water is kept fully saturated with oxygen whereas physical-chemical treatment relies on the use of chemicals to coagulate the BOD material. The material settles out of solution and then passes through sand filtration which further reduces the BOD.

Biological plants are usually more expensive to build and are less reliable especially as noted earlier where there is the potential for industrial discharges which may kill the organisms necessary for treatment. Although physical-chemical plants cost less to construct, they are more expensive to operate because of the costs of chemical additives. In addition, it is more difficult to dispose of sludge produced by the physical-chemical process.

Tertiary Treatment Processes

The final stage of treatment consists of processes that affect the composition of the sewage by removing or altering chemical constituents. Among the methods used are those that will lower the saline content of the wastewater through ion exchange or will coagulate and precipitate out unwanted components or will absorb various chemical constituents. Treating the wastewater with activated carbon is a common method of tertiary treatment. Tertiary treatment processes can be selected that will restore or improve the original quality of the water although the cost may be prohibitive.

An Alternate Method, Land Treatment

Land treatment is an alternative to the in-plant sewage treatment. Muskegon, Michigan, and several smaller communities in the United States use land treatment for their sewage disposal. In the land treatment system, the sewage is collected and stored in large retention basins that provide both primary treatment (by sedimentation) and secondary treatment (by bacterial decomposition). Oxygen is supplied by mechanical aerators that continually force air into the retention lagoons. Tertiary treatment levels are provided by spraying the effluent on the land during the growing season. The action of plants and soil provide tertiary levels of treatment. One important benefit of land treatment in some areas is the recharge that results from infiltration of the treated effluent to the groundwater table.

Sludge

Sludge is a by-product of waste-sewage treatment. It is a semi-liquid mass containing the solids from the original waste elements in the water, the organisms growing in that waste, the residual chemical compounds, and any additives used in treating the wastewater. Sludge is mostly water, approximately ninety-five percent by weight. The major problem associated with sludge treatment is to reduce its bulk by dewatering and drying.

The volume of sludge produced from primary and secondary treatment of sewage is equal to approximately three percent of the input volume of wastewater. Sludge disposal has proven to be a difficult process. Even though the untreated sludge contains valuable nutrients, it is a difficult substance to handle, odorous, and potentially dangerous because of the presence of pathogenic organisms. It also may contain heavy metals which lessen its value as a source of fertilizer. Some cities dry, disinfect, and process the sludge for use as an organic fertilizer. The city of Milwaukee uses the trade name Milorganite for its commercially prepared and packaged sludge.

In addition to selling sludge for fertilizer, it can be treated anaerobically (digested), producing methane and a residue that can be used for fertilizer. Anaerobic digestion provides a stable, safe product with a high nutrient content. The city of Chicago has been selling anaerobically digested sludge to farmers as an organic fertilizer and has experimented with the use of sludge in restoring the land surface scarred by abandoned strip mines.

Most sludge, however, is not sold but is disposed of by incineration or in land fills. Incineration can be costly because of the high water content of the sludge and today's high energy costs. Once dry, the sludge is a fuel and will support combustion, but drying the sludge to the point where it will burn requires large amounts of energy. The disposal of sludge by landfill can pollute the groundwater. Sludge disposal is one of the most intractable problems of the sewage treatment process. The inability to find a good solution should encourage greater attention to the land treatment of sewage which does not result in sludge production.

Costs of Treatment. The costs of treating wastewater to the level prescribed by P. L. 92–500 depend upon the type of processes used, the ease of sludge disposal, and, since there are significant economies of scale, the

volume of sewage treated. The larger the volume of wastewater treated the less are the costs per unit of value. Costs of treating 1000 gallons of sewage to a secondary level are almost twice as high for a million gallon a day (mgd) plant as for one that treats 10 mgd, and almost three times what it would cost if treated in a plant of 100 mgd capacity.

Estimates of the costs to build and operate a 10 mgd plant to meet the 1977, 1983, and 1985 standards using the least expensive technology were projected at 20¢/1000 gallons in 1977, 25¢/1000 gallons in 1983 and $1.10/1000 gallons in 1985 (Monti and Silberman, 1974).

These estimates were prepared in 1974 when costs of energy were less. Since waste treatment is highly energy intensive, actual costs should prove to be higher. There are large energy increases as treatment levels increase. One estimate of the effect on energy use of fully implementing the 1977 standards is that twenty percent of our national energy budget will be devoted to sewage treatment and sludge disposal (Byrd, 1974). As higher levels of BOD, COD, and non-degradable waste removal are implemented the costs undoubtedly will rise.

Meeting the Goals of P. L. 92-500 and 95-217

When Congress passed the Water Pollution Control Act Amendments, P. L. 92-500, Title II of the law authorized $18 billion to provide grants to municipalities for upgrading sewage installations. The Environmental Protection Agency is responsible for providing the grants and supervising the planning, installation, and operation of the plants. In addition, other federal funding that had been provided under previous legislation dating back to 1956 was brought under the jurisdiction of the Environmental Protection Agency. Over $20 billion of funding has been approved for wastewater facilities since 1957. Much more has been requested but the complex procedures required by the Environmental Protection Agency creates a substantial delay between the time of application and the end of construction. The entire grants process (after the prospective plant has been selected by the state as having priority) is scheduled to take over six years. Because of the delay, P. L. 95-217 has provided that the 1977 standards not be required until 1983.

Even with this length of time, the process is not working well. A survey of the adequacy of the environmental impact statements prepared as part of the planning process for forty-three plants found that none was adequate. The major deficiencies were the neglect of nonstructural alternatives and the lack of public involvement (Environmental Protection Agency, 1974).

A 1976 survey estimated that there would be 4000 sewage treatment facilities that could meet the July 1, 1977, requirements on schedule (U.S. Congress, 1977). The plants served less than one-third of all the communities with sewers and treated slightly more than one-third of the volume of wastewater produced. Of the ten Environmental Protection Agency administrative regions in the United States three will be treating over half the flow collected by mid-July, 1977 whereas one treated less than 20 percent (Figure 9).

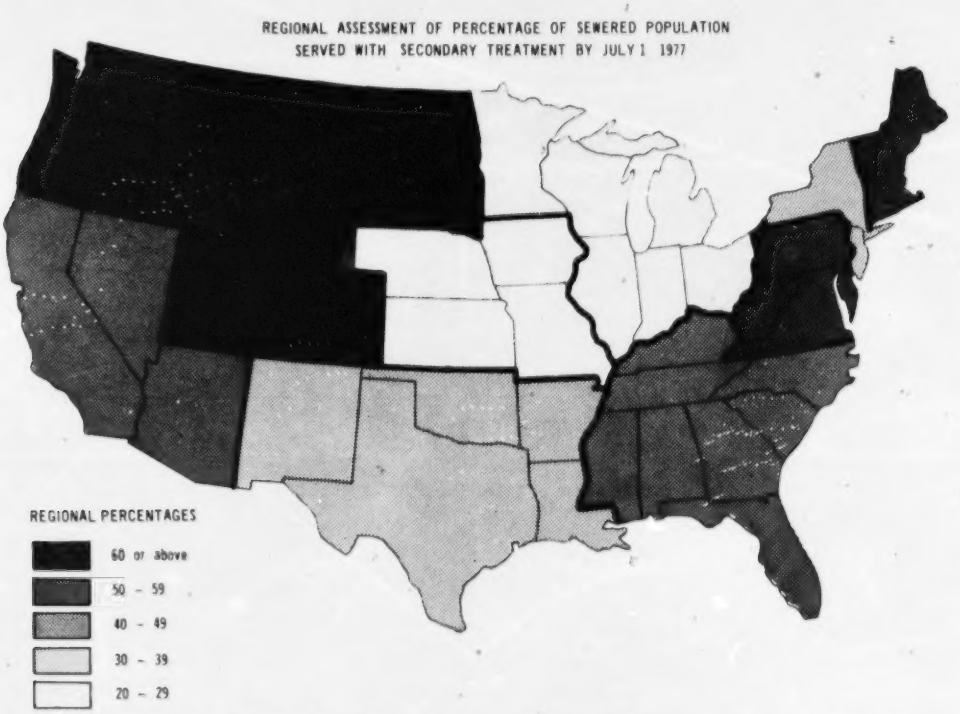
REGIONAL ASSESSMENT OF PERCENTAGE OF SEWERED POPULATION
SERVED WITH SECONDARY TREATMENT BY JULY 1 1977
REGIONAL PERCENTAGES
60 or above
50 - 59
40 - 49
30 - 39
20 - 29

Figure 9. Modified from U.S. Congress, House of Representatives, 1977.

The data on costs of meeting the P. L. 92–500 goals set for 1977 are impressive. If the levels of federal contribution are maintained at $4.5 billion annually, it will take sixteen years for plants to be built in order to meet the 1977 standards (U.S. Congress, 1977). In the past because many plants with adequate design failed to meet the design criteria for effluent quality, such an investment will assure only a partial treatment level.

The cost of meeting the 1983 goals is elusive and the cost of meeting the goal of zero discharge is in the realm of fantasy since some of the technology simply does not exist. Estimates in 1972 ranked to over $100 billion in capital costs alone (Environmental Protection Agency, 1974). Public Law 95–217 delays the requirements for meeting the 1977 standards in those cases where the financing or the planning could not be completed. The overall criticism is still valid, however, even though the timetable has been altered.

While the costs are elusive, the benefits are even less tangible. The estimate of benefits is usually based on damages derived from specific regions and cannot be generalized for the country as a whole. For example, there are estimates of the costs of increase in salinity in the Colorado River that are at best appropriate only for that basin. The damages from water pollution, moreover, are related to those caused by municipal, industrial, nonpoint sources, and those caused by natural environmental processes, such as the natural saline discharges to the Colorado River. The estimates of total economic damage for mid-1970 have been nearly $10 billion (Dee, Reiquam, and Choi, 1974).

Were municipal plants to meet the 1985 zero-discharge goal, there would still be some affecting environmental costs associated with sludge disposal. There are only three disposal methods for sludge: 1) incinertion, which causes some air pollution; 2) ocean dumping, which causes water pollution; and 3) land disposal, which may cause groundwater pollution.

In summary, there is little evidence that meeting even the 1977 goals of secondary treatment can be justified on economic grounds. The costs of doing so will require an annual capital investment of $4.5 billion and close monitoring of plant performance to maintain operating standards. The operating costs not only will be high but will be borne by the population served. At present, those communities that are operating sewage plants financed under P. L. 92–500 must collect user charges. These range from 16¢/1000 gallons in Detroit to 95¢/1000 gallons in parts of Washington, D. C. (Table 9). As yet, there is little public awareness of this new cost for municipal services since there are so few plants that have been built under the new law.

This leads to the fundamental problem of adoption. The most innovative and efficient plans are of little value if the professional planners and the public do not accept them. Hence, during the last decade researchers have directed their attention to understanding the obstacles in the adoption process.

TABLE 9. SEWER USER CHARGES, 1976

Wastewater Treatment Plants	User Charge $/100 g	Water Treated mgd	Level of Treatment
Detroit, MI	0.16	930	P + [S]
Grand Rapids, MI	0.29–0.48	45	P + S + [CP]
Lansing, MI	0.41–0.53	25 [36]	P + S + [CP + SF]
Washington, D.C.	0.36–0.56	291 [308]	P + S + CP + [N, etc.]
Suburban D.C. in MD	0.95	147	P + S + CP + [N, etc.]
East Lansing, MI	0.85	12 (19)	P + S + CP + SF
Belding, MI	0.40–1.00	0.5	Oxidation lagoons + [SI]
Muskegon Co., MI	0.22+	27 (43)	Aeration + SI

[ ] = Under construction, not yet in service or only in partial service
( ) = Capacity available but not yet utilized
P = Primary
S = Secondary
CP = Chemical precipitation of phosphate
SF = Sand filter
N = Nitrogen Treatment
SI = Spray Irrigation

Source: U.S. Congress, House of Representatives, 1977.

VI. SOCIAL ACCEPTANCE OF ALTERNATIVES: PROFESSIONAL AND PUBLIC

Professional Bias?

Faced with rising demands, dwindling sources of supply, and growing difficulties regarding quality, the professionals responsible for water system management are finding it necessary not only to justify their decisions but to enlist public support. No planning alternative or set of alternatives is truly viable without public acceptance. We cannot expect the general public to fully understand the complexities and tradeoffs involved in water system management. Furthermore professionals themselves must study and understand the alternatives before they can reasonably expect informed and effective input from the public.

In this context it is interesting to examine the issue of professional bias among decision makers. Decisions on water supply and wastewater treatment are generally reached through the interaction of elected officials, department personnel, and outside consultants. Russell, Arey, and Kates (1970:175), in a study of forty-eight Massachusetts communities indicated that "in the planning process, the scope of the debate is generally set by the consulting engineers. They define the alternatives, make the demand projections, and provide cost information." Hence in planning for municipal water supply, the values and biases of the engineer appear to be extremely influential.

The potential effects of professional socialization on choices of resource management alternatives have been known generally, but until recently have been the focus of only a few studies. Sewell and Little (1972) suggest that, unlike government officials and special interest groups, engineers are more likely to concentrate on physical problems, and choose physical construction alternatives from among a set of possible solutions. As a result, planners or engineering consultants may strive for objectivity and seek to identify the optimum strategy, but their formulation of plans and recommendations may become an exercise in rationalization that selects evidence to support a preconceived and preferred choice of action.

In another study, Sewell (1971) demonstrated that distinct differences may occur among various types of professionals in the water resource area. Both public health officials and consulting engineers, for example, reflected their particular professional biases in the area of water quality; public health officials most frequently emphasized health problems whereas engineers usually focused on increasing production costs. Furthermore, when dealing with solutions to environmental problems, public health officials relied upon issuing a warning followed by litigation, whereas engineers emphasized construction of facilities. Hence, the reliance on a few alternatives in the management of urban water supply is strongly related to professional socialization and past experience.

Another facet of acceptability relates to how professionals view the public's perception of various alernatives. This can best be illustrated in terms of the alternative reuse. Recalling the debates over fluoridation of public water supplies, and being aware of the heightened need for public participation in current water planning, water resource managers are especially concerned about public acceptance of recycled wastewater. In an unpublished report Baumann (1969) found that of the 300 municipal water managers he surveyed in the United States, the most common reason cited by the fifty percent who opposed wastewater reuse was anticipated rejection by the public. Similarly, Johnson (1971) found that "it would appear that water managers know very little of consumer responses concerning renovated wastewater, but generally consider the public would not accept it" (p. 92). If this is the case, it could be that the public becomes a scapegoat for the reluctance of engineers, water managers, public health officials, city councils, and local water boards to change the established procedures of municipal water supply provision.

Public

The recent experience in Denver seems to support the contention that the public may provide greater support for new water management alternatives than the professionals assume. In a survey of 500 people, the initial response to the concept of recycling renovated wastewater was primarily negative. However, as the respondents were provided additional information on the implications of water reuse planning, the rate of public acceptance increased until eighty-five percent of the respondents expressed a willingness to drink renovated wastewater (Heaton *et al.*, 1974). In view of this evidence, a key obstacle in the consideration and adoption of recycling renovated wastewater for municipal water supply may lie not so much in the mind of the consumer as in the perceptions of consulting engineers, public health officials, and other involved professionals.

These arguments apply generally, not only to reuse, but also to such alternatives as public adoption of conservation strategies, or acceptance of altered rate structures. It is clear that professionals will have to overcome not only public bias but also their own prejudices in making intelligent planning decisions and in finding support for those decisions.

The public will not necessarily accept those alternatives that are technically most efficient, and it may oppose optimal economic solutions on noneconomic

grounds. In recent times, a range of interest groups has emerged around broad social and environmental issues. Whether well-informed or not, these groups have already had considerable impact on public perception of issues as well as on the context in which decisions must be made. As Kneese and Schultze (1975:56) note, an important factor in developing the unprecedented strict requirements of the 1972 Federal Water Pollution Control Act

> seems to have been dedicated and highly effective work by a small number of conservationists advocating zero discharge. They seem to have felt that the more stringent the restrictions were, the cleaner the water would be, although there is absolutely no historical justification for this view.

No doubt public and congressional perceptions of the complexities of these and other environmental issues have become more sophisticated. Nonetheless, to date there has been little research on public preferences and the means by which they might be changed. It is also apparent that we need considerable public education on the implications of various issues and alternatives in municipal water management.

VII. SUMMARY AND CONCLUSIONS

Underlying the techniques and alternatives in planning for municipal water supply and wastewater management are several fundamental problems that transcend individual aspects of each component of the planning process. Four major problems deserve attention. First, there is a need to reassess some of our basic assumptions and beliefs in water management. To improve efficiency in planning we need a more *critical appraisal* of our conventional traditional wisdom. Some examples should suffice:

1) Water should be viewed as an economic good or service, not as a unique physical substance, nor as a fixed or limited resource. These views are major obstacles in communication among economists, engineers, and hydrologists. In the current water supply planning process we find the application of sophisticated engineering models but only elementary and crude economic and demographic analyses.

2) We assume that fragmentation of water supply systems is undesirable, but what is desirable? Should we have one management unit for the entire U.S., or for a river basin, or state, or economic region? Rather than assuming that regionalization is inherently good, we find that the available evidence is insufficient to determine the optimum management unit.

A second major problem includes the differing perceptions among groups of professionals. Research demonstrates that engineers view problems in physical, not social, terms, and opt for solutions which are primarily structural in nature. Similarly, public health officials are more likely to rely on warnings followed by litigation, as a solution to problems.

A third problem deals with our capability to change, not only our own ideas but our institutions. For example, although new pricing schedules might be deemed desirable, consensus is pessimistic about actual political adoption and implementation. The experience of the past is a compelling force to maintain the status quo, but such a strategy may be too costly today. We have too few suggestions that would greatly contribute to overcoming this reluctance to innovate. The problem manifests itself in another way: although there is often strong local resistance to implementing federal standards such federal involvement would not have occurred had local units responded more rapidly to our changing society.

Finally, a fourth basic problem involves the need to develop a method or model of public investment in urban water planning. Simply stated, we need to evaluate the relative benefits of every alternative, both structural and nonstructural, as well as to identify the optimal combination of alternatives for each particular urban area. Or, we can state it another way—we cannot identify an ideal, prototype management water utility because we lack an analytical model to evaluate optimum system design, process, management, and impact.

Even if all the research needs for each alternative were satisfied, we must still face the problem of identifying the optimum combination of these options at a particular place and time. Until we can formulate such a methodology, policy change will be haphazard, piecemeal, and unconvincing to many in the professional and public sectors.

The proper management of municipal water systems will require increasingly careful and sophisticated planning. The number of variables to be considered in both supply and demand is growing, and their interactions are becoming more complex. Furthermore, water quality and wastewater treatment have assumed new importance. In the future, we must give greater attention to legal, social, and environmental constraints along with the traditional engineering and economic considerations. Successful solutions to planning problems will involve the studied evaluation and balancing of alternatives; no single alternative will provide a total solution.

BIBLIOGRAPHY

Afifi, H. H. H. 1969. "Economic Evaluation of Water Supply Pricing in Illinois." *Journal of American Water Works Association*. Vol. 61, No. 1.

Alvord, Burdick, and Howson. 1937. *Report to the Indianapolis Water Company Upon an Additional Water Supply*. Chicago.

American City. 1946. "What Water Meters Did for Elizabeth City, North Carolina." Vol. 61, No. 9.

American Water Works Association. 1958. *Water Rates Manual*. New York: American Water Works Association.

_____. Committee on Water Use. 1973. "Review of the Johns Hopkins University Research Project Method for Estimating Residential Water Use." *Journal of American Water Works Association*. Vol. 65, No. 5.

Aron, G.; T. Rachford; J. Borelli; and W. Stottman. 1974. *A Method for Integrating Surface and Ground Water Use in Humid Regions*. Ft. Belvoir, Virginia: Institute for Water Resources.

Argo, D. G. 1976. "Wastewater Reclamation Plant Helps Manufacture Fresh Water." *Water and Sewage Works*. Vol. 123, Ret. 1976, pp. R 160–R 170.

Bardo, G. and M. Cassell. 1971. *Tabulation of 128 Waterborne Disease Outbreaks Known to Have Occurred in the United States 1961–1970*. Cincinnati, Ohio: U.S. Environmental Protection Agency.

Baumann, D. D. 1969. Unpublished Survey of 300 Municipal Water Managers in the United States.

Baumann, D. D., and D. M. Dworkin. 1975. *Planning for Water Reuse*. Washington, D.C.: U.S. Army Corps of Engineers, Institute of Water Resources.

_____, and R.E. Kasperson. 1974. "Public Acceptance of Renovated Waste Water: Myth and Reality." *Water Resources Research*. Vol. 10, No. 4.

Blake, N. 1956. *Water for Cities*. Syracuse, New York: Syracuse University Press.

Bonem, G. 1968. "On the Marginal Cost Pricing of Municipal Water." *Water Resources Research*. Vol. 4, No. 1.

Brown, G. M. 1968. "Industrial Water Demands: A Critique." In *Forecasting the Demands for Water*, W. R. Derrick Sewell *et al.* (ed.) Ottawa, Ontario: Policy and Planning Branch, Dept. of Energy, Mines and Resources.

Brown, H. A. 1940. "Super Chlorination at Ottumwa, Iowa." *Journal of American Water Works Association*. Vol. 32, No. 4.

Burns, D. R. J. *et al.* 1975. *The Effect of Price on Residential Water Demand: A Comparative Use Study*. In Seminar in Water Resources and Development Management: Boulder: University of Colorado.

Byrd, J. F. 1974. "Impacts and Consequences of Existing Legislation on Water Pollution." *Pollution Control Technology Assessment*. Cincinnati, Ohio: National Environmental Research Center.

Chambers, J. C.; S. K. Mullick; and D. D. Smith. 1971. "How to Choose the Right Forecasting Technique." *Harvard Business Review*. Vol. 49, No. 4.

Cillie, G. C. *et al.* 1966. "The Reclamation of Sewage Effluents to Domestic Use." *Third International Conference on Water Pollution Research*. Washington, D.C.: WPFC.

Clawson, M. 1973. *Suburban Land Conversion in the United States*. Baltimore: The Johns Hopkins Press.

Cloonan, E. T. 1965. "Meters Save Water." In *Modern Water Rates*. New York: Battenheim Publishing Company.

Comptroller General of the United States. 1973. *Improved Federal and State Programs Needed to Insure the Purity and Safety of Drinking Water in the United States*. Washington, D.C.: General Accounting Office.

_____. 1974. *Research and Demonstration Programs to Achieve Water Quality Goals: What the Federal Government Needs to Do*. Washington, D.C.: General Accounting Office.

Craun, G. F. and L. J. McCabe. 1973. "Review of the Causes of Waterborne Disease Outbreaks." *Journal of the American Water Works Association*. Vol. 65, No. 74.

Culp, R. L. and G. L. Culp. 1971. *Advanced Wastewater Treatment*. New York: Van Nostrand Rheinhold Co.

D'Angelo, A. 1964. *Report on Universal Metering*. To Honorable Robert F. Wagner, Mayor of New York City, 7 October.

Dean, R. 1965. *Transmission of Viruses by the Water Route*. New York: John Wiley & Sons.

Dee, N.; H. Reiquam; and P. Choi. 1974. *Environmental Quality Improvements Through Systematic Implementation of Pollution Controls in Pollution Control Technology Assessment*. Columbus, Ohio: National Research Center.

Dworkin, D. 1974. *The Value of Water Reuse for Municipal Supply*. Worcester, Massachusetts: Department of Geography, Clark University, Ph.D. dissertation (unpublished).

_____. 1975. "Water Use: A Flexible and Efficient Management Alternative for Municipal Supply." *Water Resources Research*. Vol. 11, No. 5.

_____. 1977. "Increased Yields of Combined Storage Reservoirs," Mimeograph Carbondale, Illinois: Department of Geography, Southern Illinois University.

_____, and D. Baumann. 1974. *An Evaluation of Water Reuse for Municipal Supply*. Washington, D.C.: Institute for Water Resources, U.S. Corps of Engineers.

Eliassen, R. and R. H. Cummings. 1948. "Analysis of Waterborne Outbreaks 1938–1945." *Journal of American Water Works Association*. Vol. 40, No. 509.

Environmenta' Protection Agency. 1974. *Review of the Municipal Waste Water Treatment Works Program*. Washington, D.C.: U.S. Government Printing Office.

Fair, G. M.; J. C. Geyer; and D. A. Okun. 1966. *Water and Waste Water Engineering*. New York: Wiley and Company.

Federal Register. 1973. Vol. 38, No. 159, pp. 22298–22299.

Gert A.; T. Rachford; J. Borelli; and W. Stottman. 1974. *A Method for Integrating Surface and Ground Water Use in Humid Regions*. Ft. Belvoir, Virginia: Institute for Water Resources.

Gottlieb, M. 1963. "Urban Domestic Demand for Water: A Kansas Case Study." *Land Economics*. Vol. 39.

Gysi, M. and D. P. Loucks. 1971. "Some Long Run Effects of Water-Pricing Policies." *Water Resources Research*. Vol. 7, No. 6.

Hanke, S. H. 1970a. "Some Behavioral Characteristics Associated with Residential Water Price Changes." *Water Resources Research*. Vol. 6, No. 5.

_____. 1970b. "Demand for Water Under Dynamic Conditions." *Water Resources Research*. Vol. 6, No. 5.

_____. 1974. "Water Rates: An Assessment of Current Issues." In *The State of America's Drinking Water*. Raleigh, North Carolina: Water Resources Research Institute.

_____, and E. Flack, Jr. 1968. "Effects of Metering Urban Water." *Journal of American Water Works Associa-*

tion. Vol. 60, No. 12.

Harris, R. D. 1974. *The Implications of Cancer-Causing Substances in Mississippi River Water*. Washington, D.C.: The Environmental Defense Fund.

Harris, R. H. and Brecker, 1974. "Is the Water Safe to Drink?" *Consumer Reports*. Vol. 39, No. 6.

Hartman, L. M. and D. Seastone, 1970. *Water Transfer*. Baltimore: The Johns Hopkins Press.

Hazen, A. 1897. *Report on the City's Water Supply*. Report to the Women's Health Protection Association of Philadelphia, Philadelphia, Pennsylvania.

Headley, C. 1963. "The Relation of Family Income and Use of Water for Residential and Commercial Purposes in the San Francisco-Oakland Metropolitan Area." *Land Economics*. Vol. 39.

Heaton, R. D.; K. D. Linstedt; E. R. Bennett; and L. G. Suhr. 1974. *Progress Toward Successive Water Use in Denver*. Paper presented at The Water Pollution Control Federation, Annual Meeting, Denver. Mimeographed.

Heggie, G. D. 1957. "Effects of Sprinkling Requirements." *Journal of American Water Works Association*. Vol. 49.

Hittman Associates, Inc. 1969. *Forecasting Municipal Water Requirements*. Columbia, Maryland: Report HIT–413.

Hirschleifer, J.; J. C. DeHaven; and J. W. Milliman. 1960. *Water Supply: Economics, Technology and Policy*. Chicago: University of Chicago Press.

Howe, C. W. 1968. "Water Pricing in Residential Areas." *Journal of American Water Works Association*. Vol. 60, No. 5.

_____, and F. P. Linaweaver, Jr. 1965. "The Impact of Price on Residential Water Demand and Its Relation to System Design." *Water Resources Research*. Vol. 1.

_____. 1967. "The Impact of Price on Residential Water Demand and Its Relation to System Design and Price Structure." *Water Resources Research*. Vol. 3.

Howe, C. W. and W. J. Vaughn, 1972. "In-House Water Savings." *Journal of American Water Works Association*. Vol. 64, No. 2.

Hudson, H. E. Jr., and R. Hazen, 1964. "Droughts and Low Streamflows." In *Handbook of Applied Hydrology*, V. T. Chow (ed.) New York: McGraw Hill.

_____, and W. J. Roberts. 1955. *1952–55 Illinois Drought with Special Reference to Impounding Reservoir Design*. Urbana, Illinois: Department of Registration and Education, Illinois State Water Survey Bulletin No. 43.

Hydrological Engineering Center. 1975. *HEC-4 Monthly Streamflow Simulation*. Davis, California: U.S. Army Corps of Engineers.

Johnson, J. F. 1971. *Renovated Waste Water: An Alternative Supply of Municipal Water Supply in the United States*. Chicago: University of Chicago, Department of Geography, Research Paper No. 135.

Kahan, A. M. 1972. "Weather Modification Progress Report." *Water Resources Research*. Vol. 64, No. 5.

Kilbourne, E.D. and W. G. Smillie. 1969. *Human Ecology and Public Health*. London: Macmillan.

Kneese, A.V. and B. T. Bower. 1968. *Managing Water Quality: Economics, Technology, Institutions*. Baltimore: The Johns Hopkins Press.

_____, and C. L. Schultze. 1975. *Pollution, Prices and Public Policy*. Washington, D.C.: Resources for the Future, Inc.

Koenig, L. 1966. *Studies Relating to Market Projections for Advanced Waste Treatment*. Washington, D.C.: U.S. Government Printing Office.

Linaweaver, F. P. Jr.; J. C. Geyer; and J. B. Wolff. 1966a. *Final and Summary Report on the Residential Water Use Research Project*. Baltimore: The Johns Hopkins University, Department of Environmental Science.

_____. 1966b. *Report on the Commercial Water Use Research Project*. Baltimore: The Johns Hopkins University, Department of Environmental Science.

_____. 1967. *A Study of Residential Water Use*. Washington, D.C.: FHA Department of Housing and Urban Development, U.S. Government Printing Office.

Linstedt, K. D. and E. Bennett. 1975. *Research Needs for the Potable Reuse of Municipal Wastewater*. Cincinnati, Ohio: U.S. Environmental Protection Agency.

Löf, G. O. G. and C. H. Hardison. 1966. "Storage Requirements for Water in the United States." *Water Resources Research*. Vol. 2, Autumn.

Malone, T. F. 1968. "Weather Modification: Present and Future." *Journal of American Water Works Association*. Vol. 60, No. 10.

McPherson, M. B. 1976. "Household Water Use." ASCE Urban Water Resources Research Program, Technical Memorandum No. 28.

Merrill, J. C. *et al*. 1967. *The Santee Recreation Project*. Cincinnati, Ohio: Federal Water Pollution Control Agency.

Metzler, D. *et al*. 1958. "Emergency Use of Reclaimed Water for Potable Supply at Chanute, Kansas." *Journal of American Water Works Association*. Vol. 50.

Meyer, A. F. 1942. *Evaporation from Lakes and Reservoirs*. St. Paul, Minnesota: Minnesota Resources Commission.

Miller, E. F. 1972. "Desalting As a Source of Water Supply." *Journal of American Water Works Association*. Vol. 64, No. 12.

Mitchell, A.; B. H. Dodge; P. Kruzic; D. C. Miller; P. Schwartz; and B. E. Suta. 1975. *Handbook of Forecasting Techniques*. Fort Belvoir, Virginia: U.S. Army Institute for Water Resources.

Monti, R. P. and P. T. Silberman. 1974. "Wastewater Systems Alternatives: What They Are . . . and What Cost?" *Water and Wastes Engineering* Reprint. Boston: Anderson-Nichols & Co., Inc.

Murray, C. and E. Reeves. 1977. *Estimated Use of Water in the United States in 1970*. Geographical Survey Circular 676. Washington, D.C.: U.S. Government Printing Office.

National Academy of Sciences. 1972. *Water Quality Criteria, 1972*. Washington, D.C.: U.S. Government Printing Office.

_____. 1977. *Drinking Water and Health*. Washington, D.C.: Safe Drinking Water Committee.

National Research Council. 1977. *Summary Report: Drinking Water and Health*. Washington, D.C.: National Academy of Sciences.

National Science Foundation. 1968. *Weather Modification*. Washington, D.C.: National Science Foundation.

Neiberger, M. 1969. "Artificial Modification of Clouds and Precipitation." *World Meteorological Organization, Technical Note No. 105*. No. 149.

Patterson, W. L. 1976. "Water Use Trends Since 1970." *Willing Water*. Vol. 20, No. 3.

Riordan, C. 1971. "Multistage Marginal Cost Model of Investment-Pricing Decisions: Application to Urban Water Supply Treatment Facilities." *Water Resources Research*. Vol. 7, No. 3.

Rowland, W. G. and A. S. Heid. 1976. "Water and the Growth of the Nation." *Journal of the Water Pollution Control Federation*. Vol. 48, No. 7.

Russell, C.; D. Arey; and R. Kates. 1970. *Drought and Urban Water Supply*. Baltimore: The Johns Hopkins Press.

42

Schmidt, C. J.; I. Kugelman; and E. V. Clements III. 1975. "Municipal Wastewater Reuse in the United States." *Journal of the Water Pollution Control Federation*. Vol. 47, No. 9, pp. 2229–2245.

Science. 1977. "Drinking Water: Health Hazards Still Not Resolved." June 24, p. 1421.

Seagraves, J. A. 1973. "Industrial Waste Charges." *Journal of the Environmental Engineering Division*, ASCE, Proceedings.

Seidel, H. G. and E. R. Baumann 1957. "A Statistical Analysis of Water Works Data for 1955 Data." *Journal of American Water Works Association*. Vol. 49.

Sewage Commission of Baltimore. 1897. *Report of the Sewage Commission of The City of Baltimore*. Baltimore, Maryland.

Sewell, W. R. D. 1971. "Environmental Perception of Engineers and Public Health Officials." *Environment and Behavior*. Vol. 3, March.

_____, and B. Little. 1972. "Specialists, Laymen, and the Process of Environmental Appraisal." *Regional Studies*. Vol. 6.

Sherwani, J. K. 1964. "Urban and Industrial Water Supply: Prospects and Possibilities." *Proceedings of Annual Meeting of American Water Resources Association*.

Simmons, J. 1966. "Economic Significance of Unaccounted-for Water. *Journal of American Water Works Association*." Vol. 43.

Sims, J. H. and D. D. Baumann, 1974. "Renovated Waste Water: The Question of Public Acceptance." *Water Resources Research*. Vol. 10, No. 4.

_____. 1976. "Professional Bias and Water Use." *Economic Geography*. Vol. 52, No. 1.

Southern Water Conservation District. n.d. Pueblo, Colorado. Brochure No. 7.

Stander, G. J. 1969. "Water Reclamation in Windhoek." *Scientiae*. Vol. 10.

State of California. 1974. "The California Water Plan: Outlook in 1974." The Resources Agency, Bulletin 160–74.

Symons, E. 1954. "Design Criteria: Part I." *Water and Sewage Works*. May, 1954.

Taubenfeld, H. 1967. "Weather Modification and Control: Some International Legal Implications." *California Law Review*. Vol. 55.

U.S. Bureau of the Census. 1975. *Statistical Abstract of the United States*. Washington, D.C.: U.S. Government Printing Office.

U.S. Congress, Federal Water Pollution Control Act Amendments of 1972, Public Law 92–500, 92nd Congress, S. 2770, 18 October.

U.S. Congress, House of Representatives. 1977. *Hearings before the Subcommittee on Water Resources of the Committee on Public Works on H.R. 3199*. Washington, D.C.: U.S. Government Printing Office.

U.S. Congress, Safe Drinking Water Act. 1974. 93rd Congress, S. 433 and H. R. 1059.

U.S. Environmental Protection Agency, Office of Water Supply. 1977. *Survey of Operating and Financial Characteristics of Community Water Systems*. Washington, D.C.: (EPA–570/9–77–03), 1977, prepared by Temple, Barker and Sloane, Inc.

U.S. Federal Water Resources Council. 1968. *The Nation's Water Resources*. Washington, D.C.: U.S. Government Printing Office.

U.S. Geological Survey. 1975. *Estimated Use of Water in the United States in 1975*. Washington, D.C.: U.S. Geological Survey.

U.S. National Water Commission. 1973. *Water Policies for the Future*. Washington, D.C.: U.S. Government Printing Office.

U.S. Public Health Service. 1962. *Drinking Water Standards*. Washington, D.C.: U.S. Public Health Service.

_____. 1970. *Community Water Supply Study*. Washington, D.C.: U.S. Public Health Service.

U.S. Water Resources Council. 1978. *The Nation's Water Resources: The Second National Assessment*. Summary Report, Draft Copy. Washington, D.C.: U.S. Water Resources Council.

Washington Suburban Sanitary Commission. 1978. "New WSSC Water/Sewer Rate Schedule." Washington, D.C.: WSSC.

Weibel, S.R.; T.R. Dixon; R.B. Weidner; and J. McCabe. 1964. "Waterborne Disease Outbreaks 1946–1960." *Journal of American Water Works Association*. Vol. 56.

White, G. F. (ed.) 1969. *Water, Health and Society: Selected Papers by Abel Wolman*. Bloomington, Indiana: Indiana University Press.

_____. 1970. *Strategies of American Water Management*. Ann Arbor: The University of Michigan Press.

_____. 1973. "Public Opinion in Planning Water Development." In *Environmental Quality and Water Development*. Edited by C. Goldman; J. McEvoy III; and P. Richardson. San Francisco: W. H. Freeman and Co.

_____, and J. E. Haas. 1975. *Assessment of Research on Natural Hazards*. Cambridge: MIT Press.

Whitford, P. W. 1972. "Residential Water Demand Forecasting." *Water Resources Research* Vol. 8, No. 4.

Wolff, L. and Geyer. 1966. *Commercial Water Use*. Baltimore: The Johns Hopkins Press.

Wollman, N. 1968. *The Water Resources of Chile*. Baltimore: The Johns Hopkins Press.

_____, and G. W. Bonen. 1971. *The Outlook for Water*. Baltimore: The Johns Hopkins Press.

43

ASSOCIATION OF AMERICAN GEOGRAPHERS

Commission on College Geography Publications

Resource Papers*

1. *Theories of Urban Location*, B. J. L. Berry, 1968
2. *Air Pollution*, R.A. Bryson, J. E. Kutzbach, 1968
3. *Perspectives on Geomorphic Processes*, G. H. Dury, 1969
4. *Spatial Diffusion*, P. R. Gould, 1969
5. *Perception of Environment*, T. F. Saarinen, 1969
8. *The Political Organization of Space*, E. W. Soja, 1971
9. *An Introduction to Spatial Allocation Analysis*, A.J. Scott, 1971
10. *Man and Nature*, Yi-Fu Tuan, 1971
11. *Tropospheric Waves, Jet Streams, and United States Weather Patterns*, J. R. Harman, 1971
12. *The Spatial Structure of Administrative Systems*, B. H. Massam, 1972
14. *The Periglacial Environment, Permafrost, and Man*, L. W. Price, 1972
15. *Conservation, Equilibrium, and Feedback Applied to Atmospheric and Fluvial Processes*, J. N. Rayner, 1972
16. *Metropolitan Neighborhoods: Participation and Conflict Over Change*, J. Wolpert, A. Mumphrey, J. Seley, 1972
17. *Computer Cartography*, T. K. Peucker, 1972
18. *Society, The City, and The Space-Economy of Urbanism*, D. Harvey, 1972
19. *Thematic Cartography*, P. Muehrcke, 1972
20. *Man and Environment*, K. Hewitt, F. K. Hare, 1972
21. *The Use of Radar Imagery in Climatological Research*, A. Williams, Jr., 1973
22. *Misused and Misplaced Hospitals and Doctors*, P. deVise, 1973
23. *Visual Blight in America*, P. Lewis, Yi-Fu Tuan, D. Lowenthal, 1973
24. *Values in Geography*, A. Buttimer, 1974
25. *Participation, Decentralization, and Advocacy Planning*, R. E. Kasperson, M. Breitbart, 1974
26. *Interurban Systems and Regional Economic Development*, W. B. Stöhr, 1974
27. *Major Job-Providing Organizations and Systems of Cities*, A. R. Pred, 1974
28. *The Underdevelopment and Modernization of the Third World*, A.R. de Souza, P. W. Porter, 1974

General Series*

10. *Geography in the Two-Year Colleges*, Panel on Geography in the Two-Year Colleges, 1970
12. *Planning College Geography Facilities*, R. H. Stoddard, 1973
13. *Perspectives on Environment*, Panel on Environmental Education; I. R. Manners and M. W. Mikesell, editors, 1974

Resource Papers for College Geography

1975 Series

RP 75-1. *Land Use Control: Interface of Law and Geography*, R. H. Platt
RP 75-2. *The Outer City: Geographical Consequences of the Urbanization of the Suburbs*, P. O. Muller
RP 75-3. *Triumph or Triage? The World Food Problem in Geographical Perspective*, C. G. Knight, P. Wilcox
RP 75-4. *Maps, Distortion, and Meaning*, M. S. Monmonier

1976 Series

RP 76-1. *The Geography of International Tourism*, I. M. Matley
RP 76-2. *Social Aspects of Interaction and Transportation*, F. P. Stutz
RP 76-3. *Landscape in Literature*, C. L. Salter, W. J. Lloyd
RP 76-4. *Geography and Mental Health*, C. J. Smith

1977 Series

RP 77-1. *Urbanization and Environmental Quality*, T. R. Lakshmanan, L. R. Chatterjee
RP 77-2. *Changing Migration Patterns Within The United States*, C. C. Roseman
RP 77-3. *Spatial Perspectives on School Desegregation and Busing*, J. D. Lord
RP 77-4. *Energy: The Ultimate Resource?*, E. Cook

1978 Series

RP 78-1. *The Geography of Crime and Violence: A Spatial and Ecological Perspective*, D. E. Georges
RP 78-2. *Water Resources for Our Cities*, D. D. Baumann, D. Dworkin
RP 78-3. *Environmental Impact Statements*, M. R. Greenberg, R. Anderson, G. W. Page
RP 78-4. *Spatial Aspects of Aging*, R. F. Wiseman

For information on these publications, write to: Association of American Geographers, 1710 Sixteenth Street, N.W., Washington, D.C. 20009.

*Out-of-print Commission on College Geography Publications are available in hard cover and in microfiche from ERIC/ChESS, 855 Broadway, Boulder, CO 80302.

Consulting Services Publications
available from

Association of American Geographers
1710 Sixteenth St., N.W.
Washington, D.C. 20009

Geography as a Discipline, R. Huke, V. Malmstrom, 1973
Sources of Funds for College Geography Departments. S. J. Natoli, 1973
Planning College Geography Facilities: Guidelines for Space and Equipment (CCG General Series Publication No. 12), R. H. Stoddard, 1973
Community Internships for Undergraduate Geography Students, K. E. Corey, A. W. Stuart, 1973
Undergraduate Program Development in Geography, T. Burke, 1973
Geography in the Two-Year Colleges (CCG General Series Publication No. 10), Panel on Geography in the Two-Year Colleges, 1970